SEWAGE AND INDUSTRIAL WA

JOURNAL of the FEDERATION OF SEWAGE AND INDUSTRIAL WASTES

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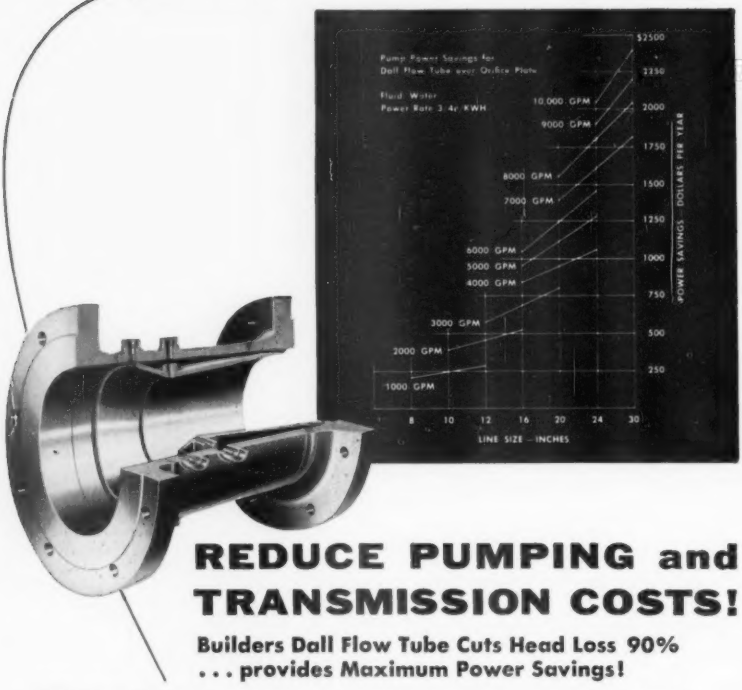

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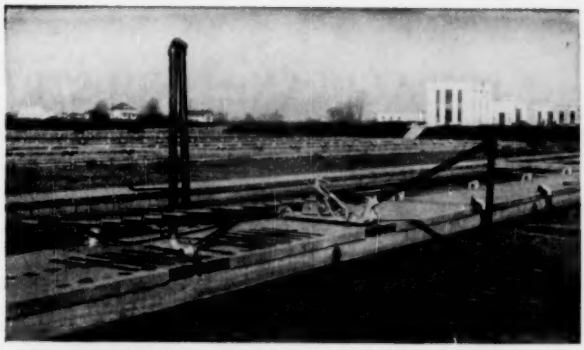

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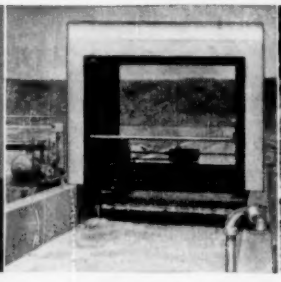

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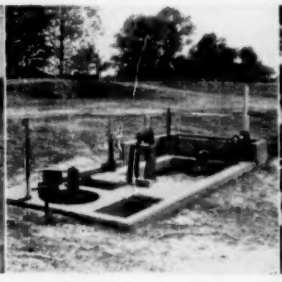

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Journal of the Federation of Sewage and Industrial Wastes Associations

Volume 31 **January 1959** **Number 1**

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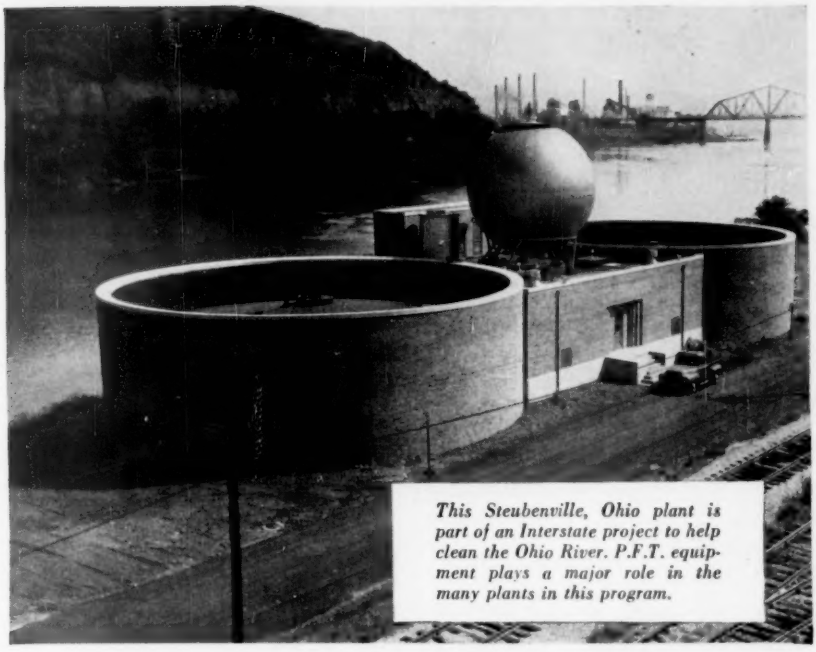

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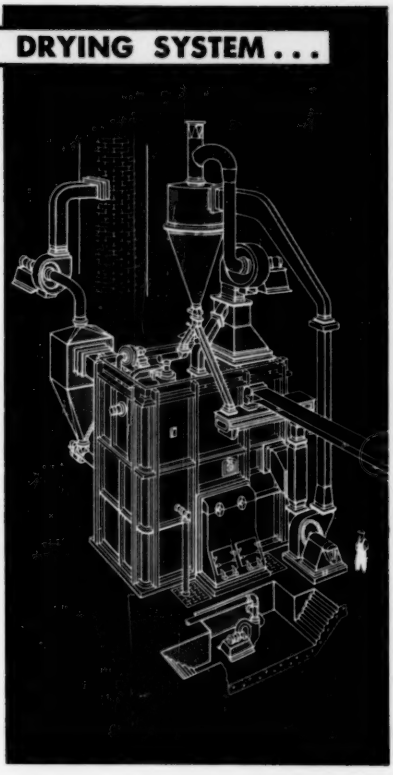

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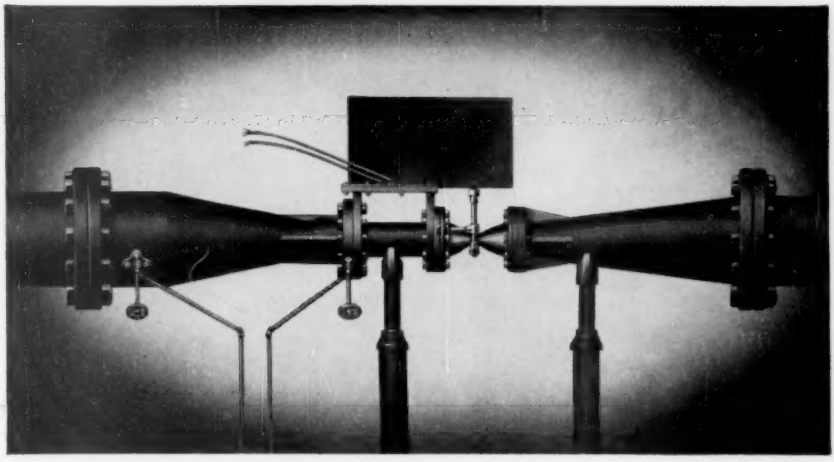

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Texas Water and Sewage Works Assn.	Texas A & M College College Station, Tex.	Mar. 1–6, 1959
Mississippi Sewage and Industrial Wastes Assn.	Robert E. Lee Hotel Jackson, Miss.	Mar. 6, 1959
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Louisiana Conf. on Water Supply and Sewerage	Louisiana State Univ. Baton Rouge, La.	Mar. 18–20, 1959
Montana Sewage and Industrial Wastes Assn.	Jordan Hotel Glendive, Montana	Apr. 9–11, 1959
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California Sewage and Industrial Wastes Assn.	Lafayette Hotel Long Beach, Calif.	Apr. 29– May 2, 1959

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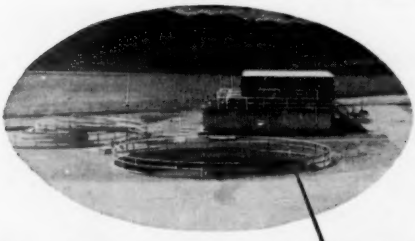

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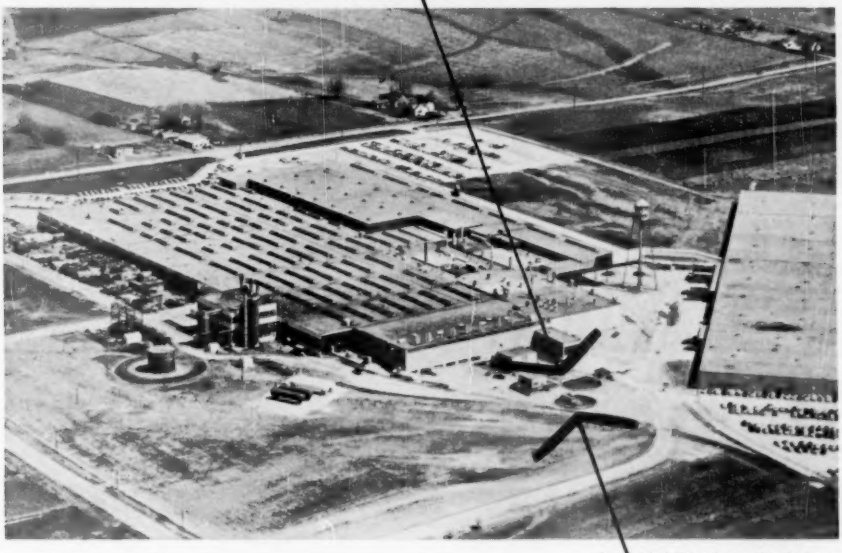

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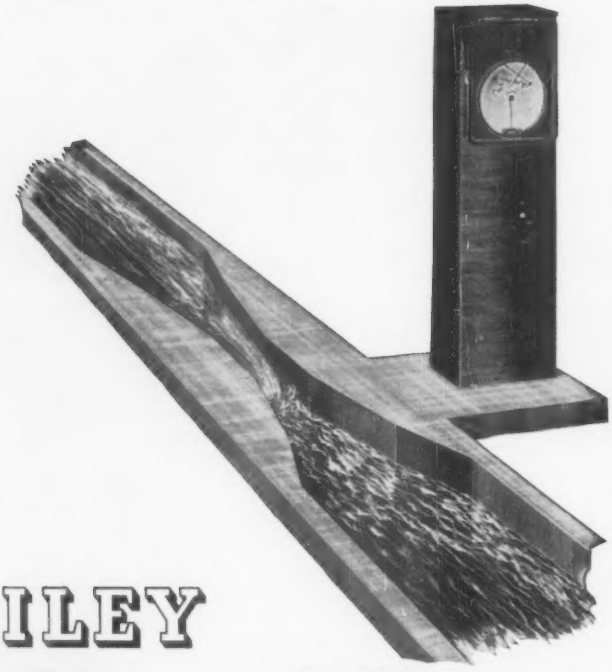

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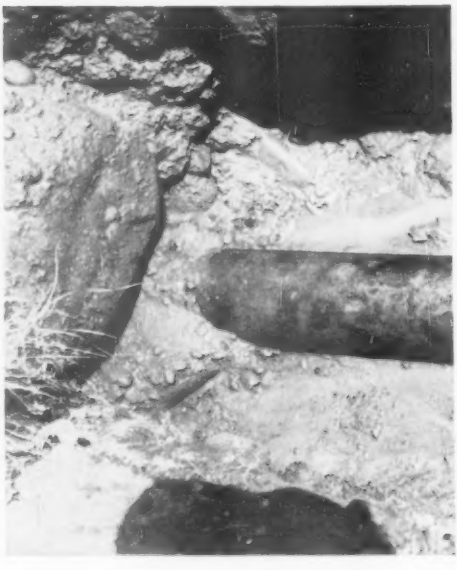

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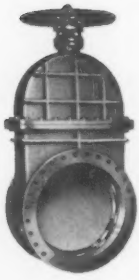

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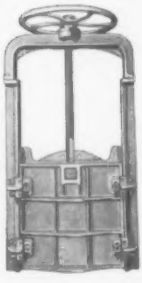

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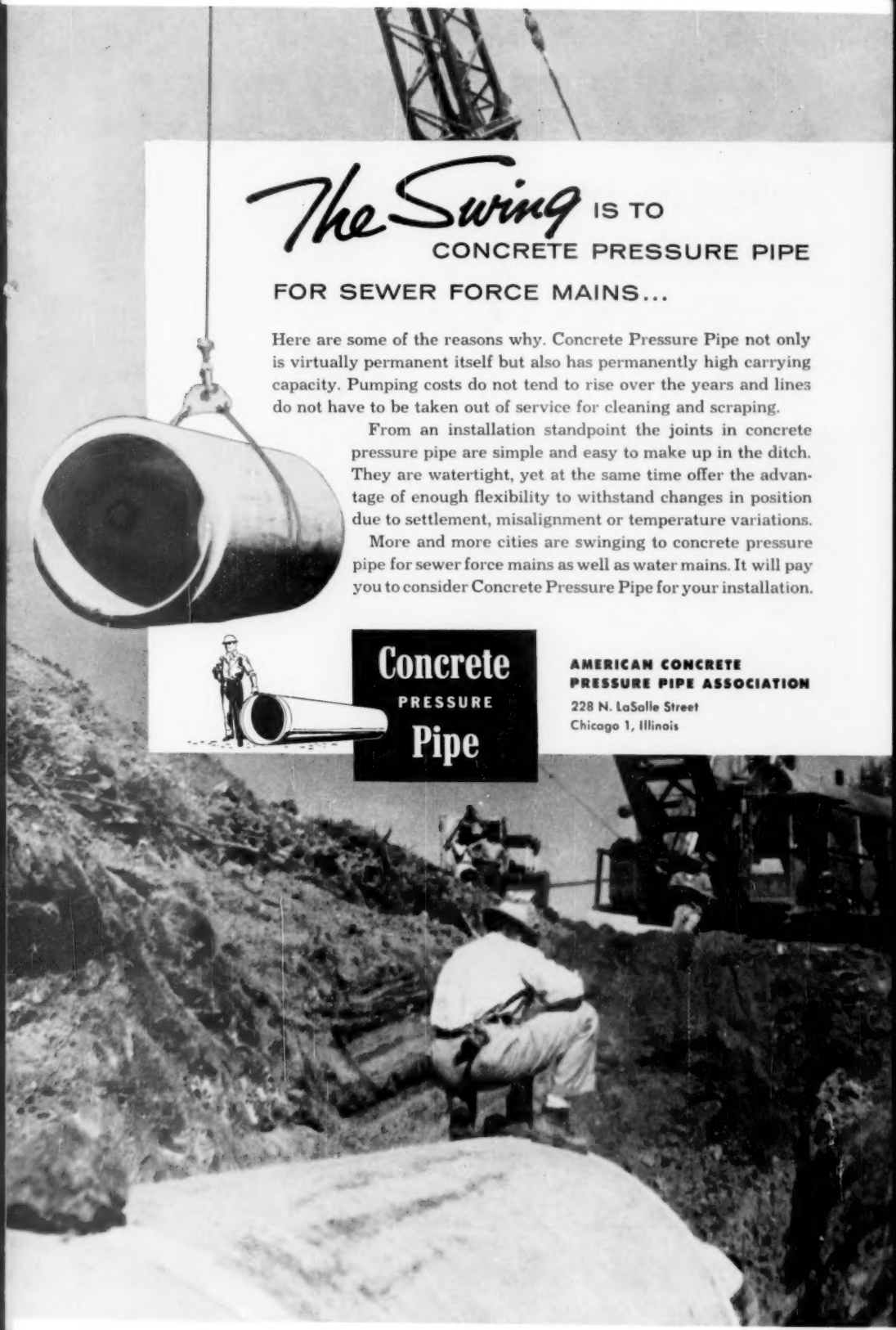

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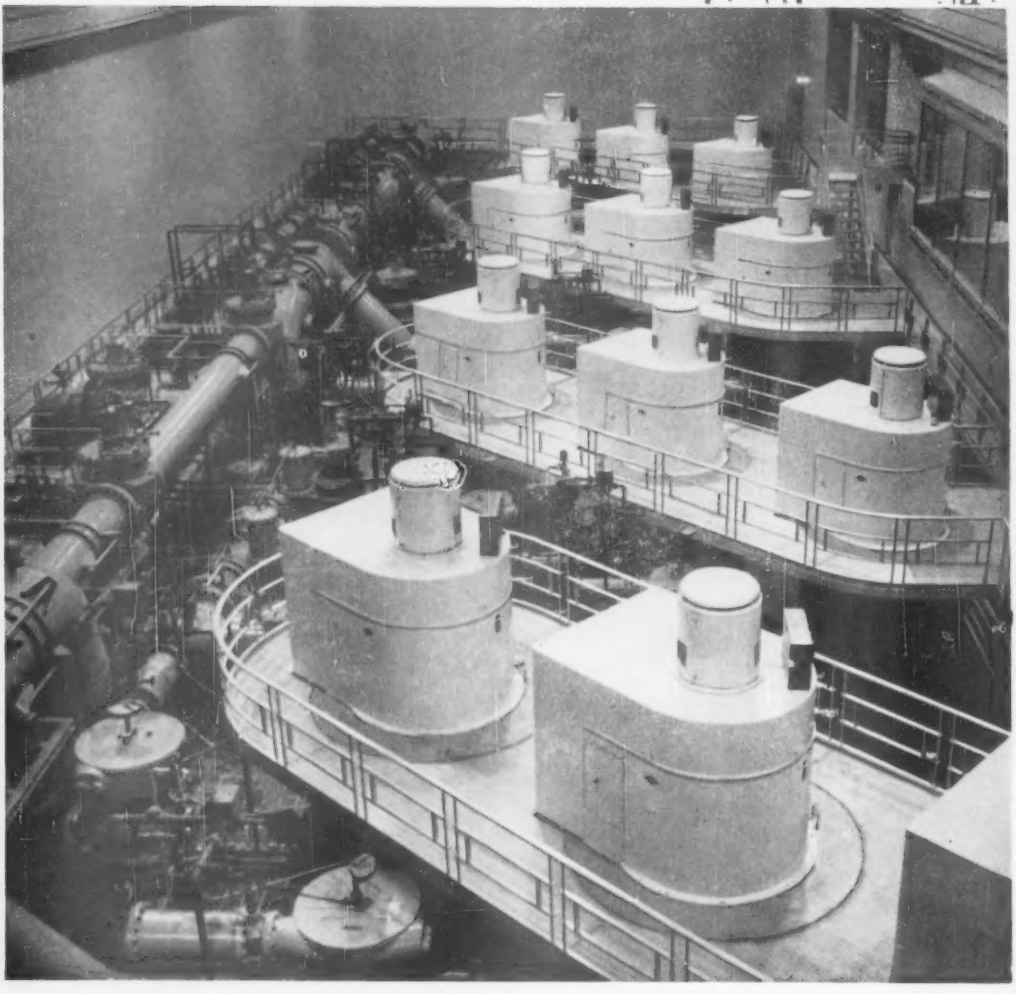

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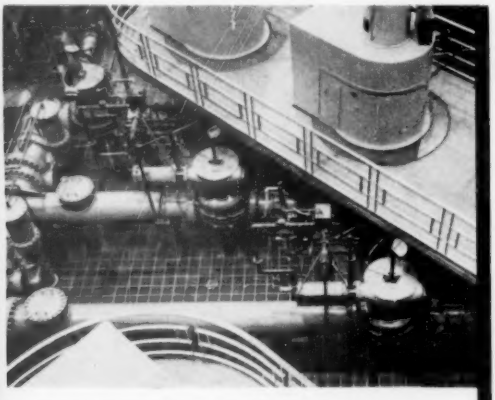

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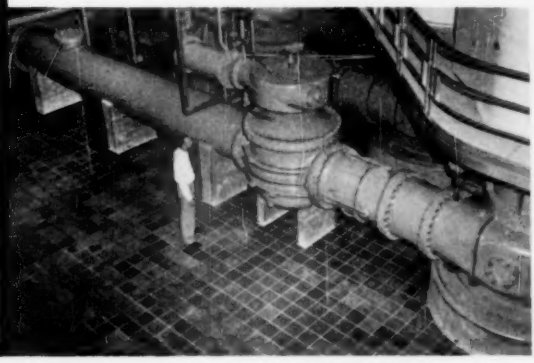

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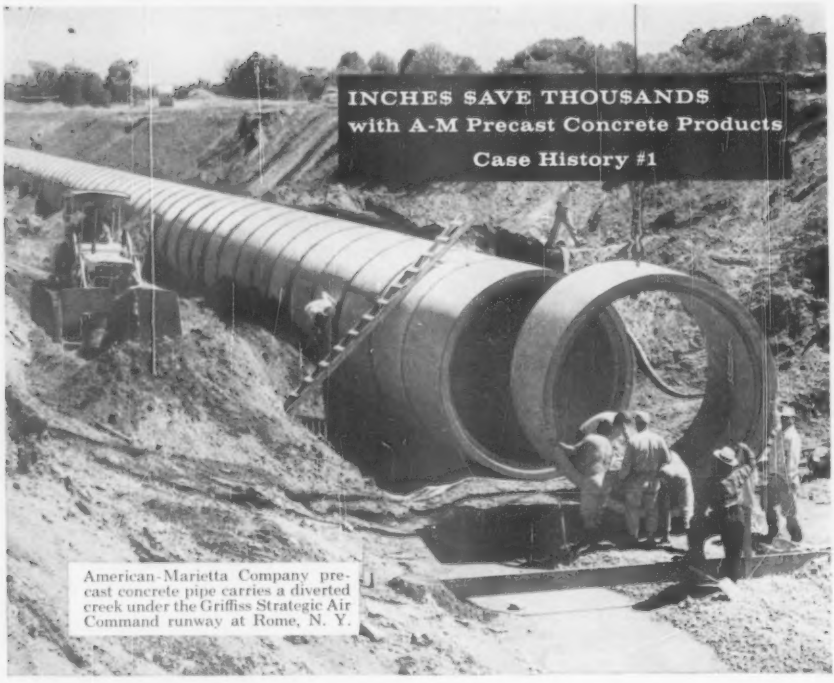
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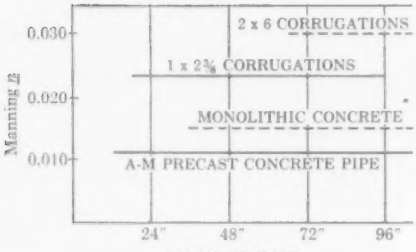

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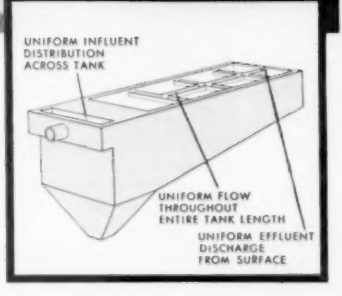
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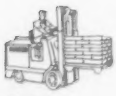

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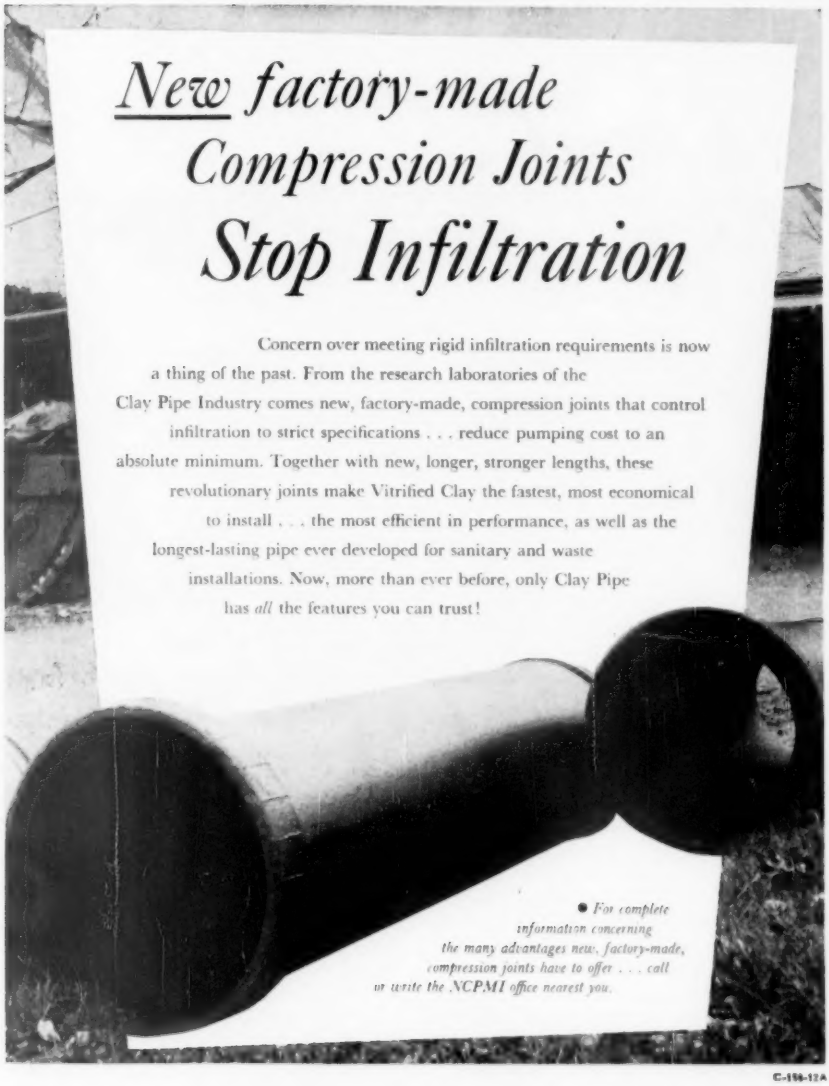
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Sewage Works

SEWAGE TREATMENT NEEDS OF THE UNITED STATES*

By Gordon E. McCallum and John R. Thoman

Respectively, Chief and Senior Sanitary Engineer, Water Supply and Water Pollution Program, Public Health Service, Department of Health, Education, and Welfare, Washington, D. C.

The cost of needed waste treatment works is an ever-present question in the forefront of planning for conservation of the quality of our Nation's water resources. How much must be spent to meet the current backlog of needs? What must be spent to meet growing population and urbanization requirements? How much must be spent to remodel and replace facilities that become obsolete? How much will plants to treat industrial wastes add to over-all pollution control costs? Answers to these and other similar questions must be provided if intelligent planning is to be done.

In this paper, one part of the over-all water pollution control needs is examined—the backlog of municipal sewage treatment. The consideration of needs is based on positive reports from state water pollution control agencies, not on any arbitrary criteria applied uniformly throughout the United States. The reports represent judgment in individual cases by officials best qualified to determine local requirements. They are needs that exist now. No attempt has been made for purposes of this study to project any future requirements.

For the last twenty years, the Public Health Service, in cooperation with state health and water pollution control authorities, has compiled and published an inventory of sewage disposal systems in the United States. Beginning in 1953, the state reporting agencies were requested to define current needs for sewage treatment in those communities having sewer systems. These requirements were reported on a coded basis as follows:

0—New treatment facilities: A plant is needed where none now exists.

1—Enlargement of existing facilities: Expansion of present facilities and processes is required. The addition of new or different processes is precluded.

2—Additions: Addition of other treatment methods or processes is needed.

3—Chlorination: Self-explanatory.

4—Replacement of existing plant: The present plant is to be completely replaced and no longer used.

5—Improved operation or utilization of existing facilities: Self-explanatory.

6—Connection to adequate existing sewer system: Self-explanatory.

7—No needs.

In some instances the reporting agency gave multiple responses to this needs question. To arrive at additive tables it was necessary to arbitrarily select one alternative only, and in such cases, the lower code number was selected. Such arbitrary selections were few, and have not significantly affected the data.

* Presented at the 31st Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Detroit, Mich.; Oct. 6–9, 1958.

Summarized data on municipal sewage treatment needs from the 1957 *Inventory of Municipal and Industrial Wastes Facilities* (1) have recently been reported (2) in detail. In this study only summary tables are presented. In addition, the estimated cost of the needed facilities is given.

Methods

The data reported in the "Inventory" were summarized by states, population groups based on the census population of the community, and major drainage basins. Only actual reports were summarized, and these were then extrapolated for an entire group on the basis of reported experience within that grouping. This type of extrapolation produces summary data which vary slightly, depending on the original data arrangement. Consequently, one extrapolation was adopted as standard, and all others adjusted to it to present uniform data. The procedures used are explained in detail in the published report (2).

Reporting of needs data in the "Inventory" was quite complete. Nationally, the reports received covered 87.7 per cent of the treatment plants serving 89.7 per cent of the population, and 89.4 per cent of the systems which discharged raw sewage. Data for raw sewage discharges represent 72.1 per cent of the population so served.

The quantification of these needs in terms of current dollars was accomplished using recently prepared per capita cost curves. These cost data were developed from contract award information available to the Public Health Service for those plants constructed with financial assistance under the Federal Water Pollution Control Act (P. L. 660, 84th Congress).

Briefly, the per capita cost data were analyzed on an area basis, where each project cost was reduced to a 1913-dollar base using the *Engineering News-Record* Construction Cost Index for one of the twenty cities where such information is compiled. For purposes of this paper, the costs were then expanded to 1957 dollars, using the U. S. Construction Cost Index for that year. In obtaining the costs by drainage basins, differences in regional costs were taken into account.

All per capita costs were applied to the needs data by population groups. The costs of primary and secondary treatment were obtained for plants serving 500 and 100,000 persons and at the mid-points of the remaining six population groups.

The cost of needs for existing plants was obtained, using the following criteria. It was assumed that primary and secondary treatment would be replaced by the same degree of treatment. Replacement of present minor (less than sedimentation) and intermediate treatment plants was raised one degree of treatment to primary and secondary, respectively. Additions and enlargements of existing plants were computed at one-half the cost of replacement or new plant construction. Connections to adequate systems were assumed to require a complete new plant.

New plants for systems now discharging raw sewage were allocated to primary and secondary treatment depending on present experience as determined from the recent summary of the 1957 "Inventory" (3). Connections to adequate systems for those systems discharging raw sewage were apportioned in a similar fashion.

In present usage the term "sewage treatment works" includes interceptors and outfall sewers as well as the treatment plant. Since these needs were not reported in the "Inventory," an estimation was required.

Contract award data collected by the Public Health Service for the years 1952 to 1957 (4) were examined to determine the relationship between new plant and interceptor-outfall construction. For these six years, con-

tracts for interceptors and outfalls were 93.4 per cent of the dollar value of new plant construction. This percentage factor was applied to the total amount for replacements, new plants, and connections to adequate systems to estimate costs of needed interceptors and outfalls. It was assumed that plants requiring enlargements or additions were adequately served by interceptors and outfall sewers.

Finally, the estimated construction contract costs developed were increased by 25 per cent to provide for land, legal, architectural, and engineering expenses and for the costs associated with financing. In 1948, Velz (5) cited 80 to 85 per cent of the bonded cost of a project as representing the actual construction contract value. The use of one-fifth the total project cost for these additional items appears to be reasonable.

The total cost of the backlog of municipal sewage treatment needs developed by the methods described above and based on present populations and present experience is considered conservative.

This backlog is not a complete picture in that future treatment needs are not included. The factors of obsolescence, great population increases, the trend towards more urbanization, the need for treatment exceeding that obtained through existing secondary processes, and the needs occasioned by increased industrial wastes loadings on community sewer systems are not taken into account. Furthermore, the assumption that the degree of treatment provided by new plant construction would follow existing practice is a conservative one since recent indications show secondary treatment is being provided in a greater proportion of new plants than was the case when existing plants were built.

The treatment costs for unsewered communities have not been estimated. Experience thus far in administering construction grant features of P. L. 660 indicates that one in five projects approved is for a previously unsewered community.

The study of per capita treatment plant costs revealed one other factor of particular interest to this analysis. It indicated a substantial reduction, on a constant dollar basis, from similar costs ten years ago. Preliminary analysis shows a decline of at least 25 per cent.

Data Included

Summarized data on municipal sewage treatment needs are presented in five tables showing the number of systems or plants and the estimated population connected within each category of needs. Tables I and II are United States totals for communities now having treatment plants and for systems now discharging raw sewage, respectively. Table III is arranged by present degree of treatment, and Tables IV and V present needs data by various types of processes within the primary and secondary degree of treatment classifications, respectively.

The cost of needed municipal sewage treatment projects is shown in Tables VI, VII, and VIII. These data are arranged by category of needs for the United States in Table VI, and total costs by population size groups and by major drainage basins are given in Tables VII and VIII, respectively.

The Backlog

Total Needs

Almost 4,000 new plants are needed to serve 22.2 million persons. Most of these are required to serve systems now discharging raw sewage, but over 1,100 new plants to serve 3.4 million persons are required to replace existing plants. This is about 15 per cent of all existing treatment plants in the United States. Today, one plant in seven needs replacement, while in 1950 only one in ten municipal plants needed replacement—a substantial rise in relative numbers. See Tables I and II.

TABLE I.—Needs of Existing Treatment Plants*

Need	Number of Plants	Est. Pop. Served (1,000's)
Replacement	1,123	3,448
Enlargement	779	17,001
Additions	851	8,370
Chlorination	44	696
Improved operation	366	992
Connection to adequate system	24	66
None	4,331	45,871

* Extrapolated on basis of reported needs.

TABLE II.—Needs of Existing Raw Sewage Discharge Systems*

Need	Number of Systems	Est. Pop. Served (1,000's)
New plants	2,851	18,725
Connection to adequate system	40	861
None	157	2,332

* Extrapolated on basis of reported needs.

In addition to new and replacement plant requirements, 779 plants serving 17.0 million persons require enlargement, and 851 plants serving 8.4 million persons need the addition of new treatment units or processes.

Adding the needs for replacements, additions, and enlargements and connection to adequate systems indicates that one plant in three is inadequate for present-day needs, let alone adequate for the rapidly increasing population of the United States. These inadequate plants serve a present total of 28.8 million persons.

About 19.6 million persons served by systems discharging raw sewage need new plants or connection to adequate systems. When this population is added to that served by inadequate plants, the total is 48.4 million persons. This is almost half of the people served by community sewer systems in the United States.

The cost, in 1957 dollars, of these needs is estimated at about $1.8 billion, of which $1.4 billion is required for completely new treatment plants including interceptors and outfall sewers. The cost of additions and enlargements is estimated to be about $321 million.

Needs by Degree of Treatment

Extrapolated needs data for plants classified by degree of treatment are presented in Table III. Twenty-nine per cent or 795 of 2,730 primary treatment plants require replacement; however, they serve only 5.2 per cent of the population served by primary treatment. Only 6.5 per cent of secondary plants require replacement. Enlargement of existing plants is a major need for all degrees of treatment. About 9 per cent of the primary plants, 13.0 per cent of intermediate plants, and 11.3 per cent of secondary plants require enlargements. In the aggregate, these plants serve 17.0 million persons.

TABLE III.—Needs of Existing Treatment Plants Arranged by Degree of Treatment*

Need	Minor		Primary		Intermediate		Secondary		Total	
	No. of Plants	Est. Pop. Served	No. of Plants	Est. Pop. Served	No. of Plants	Est. Pop. Served	No. of Plants	Est. Pop. Served	No. of Plants	Est. Pop. Served
Replacement	17	925,240	795	1,324,379	7	72,671	304	1,125,870	1,123	3,448,160
Enlargement	2	106,233	241	7,076,726	13	1,200,405	523	8,617,349	779	17,000,713
Additions	13	682,967	531	5,109,003	24	1,000,537	283	1,578,146	851	8,370,653
Chlorination	—	—	24	543,238	—	—	20	152,441	44	695,679
Improved operation	—	—	96	442,389	—	—	270	549,622	366	992,011
Connection to adequate system	—	—	6	15,927	—	—	18	49,838	24	65,765
None	9	145,890	1,037	11,155,083	56	3,317,339	3,229	31,252,438	4,331	45,870,750

* Extrapolated on basis of reported needs.

TABLE IV.—Needs of Existing Primary Treatment Plants*

Need	Septic Tank Plants		Imhoff Tank Plants		Mechanically Cleaned Tank Plants		Plain Settling Tank Plants		Others, Unknown, and Not Stated		Total	
	No. of Plants	Est. Pop. Served	No. of Plants	Est. Pop. Served	No. of Plants	Est. Pop. Served	No. of Plants	Est. Pop. Served	No. of Plants	Est. Pop. Served	No. of Plants	Est. Pop. Served
Replacement	480	616,549	234	390,283	33	218,974	24	51,966	24	46,607	795	1,324,379
Enlargement	46	81,219	118	869,761	56	6,069,260	13	32,859	8	23,627	241	7,076,726
Additions	95	146,412	307	761,799	97	2,988,272	12	1,131,925	20	80,595	531	5,109,003
Chlorination	3	3,937	3	5,180	17	516,705	—	—	1	17,416	24	543,238
Improved operation	8	5,043	67	68,895	19	365,051	1	400	1	3,000	96	442,389
Connection to adequate system	3	7,446	3	8,481	—	—	—	—	—	—	6	15,927
None	145	125,955	352	1,241,663	434	8,488,154	30	127,235	76	1,172,076	1,037	11,155,083

* Extrapolated on basis of reported needs.

As might be expected, few secondary treatment plants require additions. However, almost one-fourth of the intermediate plants and one-fifth of the primary plants require new units or processes. About 70 per cent of secondary plants, serving 31.3 million persons, have no requirements. With the very significant increases reported (3) for secondary treatment during the 1948–57 period, this is expected.

Primary Treatment Needs

A complete breakdown of extrapolated needs for various types of existing primary treatment plants is presented in Table IV.

More than half, 61.5 per cent, of present septic tank plants require replacement and these plants serve 62.5 per cent of the population served by septic tanks. Twenty per cent of the present Imhoff tank plants require replacement; however, they serve only 12 per cent of the total population connected to Imhoff tank plants. Only 33—5.0 per cent—of the primary plants having mechanically cleaned settling tanks require replacement.

Almost one-third of the population served by primary plants having mechanically cleaned basins is connected to plants requiring enlargement, and over one-fourth of the population served by Imhoff tank plants is served by plants needing enlargement. Addition of other processes or units is required by almost 15 per cent of the mechanically cleaned tank plants and by 28.3 per cent of the Imhoff plants.

Secondary Plant Needs

Table V shows extrapolated needs data for various types of secondary treatment plants. While 70 per cent of the plants and population served have no needs, significant needs exist in the remaining plants.

Over 5.2 million persons are served by 80 activated sludge plants that need enlargement, and 2.1 million persons are served by 248 standard-rate trickling filter plants that have similar requirements.

Almost 20 per cent of the sand filter plants require replacement, as do 17.1 per cent of the land application plants and 6.7 per cent of the oxidation ponds. The oxidation ponds needing replacement serve 16.0 per cent of the population served by such plants.

Costs

As previously stated, the cost of eliminating the backlog of sewage treatment needs for the United States is shown in Table VI by type of requirement. Total cost data arranged by population groups and by major

TABLE V.—Needs of Existing Secondary Treatment Plants*

Need	Act. Sludge		Trick. Filter Standard-rate		Trick. Filter High-rate		Sand Filter	
	No. of Plants	Est. Pop. Served	No. of Plants	Est. Pop. Served	No. of Plants	Est. Pop. Served	No. of Plants	Est. Pop. Served
Replacement	16	223,361	90	340,300	21	88,489	76	78,795
Enlargment	80	5,237,372	248	2,106,229	64	617,621	47	241,099
Additions	14	385,694	141	677,484	32	273,611	37	138,087
Chlorination	2	34,713	4	16,220	10	99,191	1	312
Improved operation	24	69,435	137	276,616	28	118,434	46	47,988
Connection to adequate system	3	6,792	3	23,247	6	10,613	1	1,072
None	450	18,796,363	1,247	5,910,966	651	4,754,885	186	322,845

Need	Land Application		Oxidation Ponds		Others and Unknown		Total	
	No. of Plants	Est. Pop. Served	No. of Plants	Est. Pop. Served	No. of Plants	Est. Pop. Served	No. of Plants	Est. Pop. Served
Replacement	58	129,750	29	121,500	14	143,675	304	1,125,870
Enlargement	28	280,384	28	59,468	28	75,176	523	8,617,349
Additions	37	63,147	19	31,915	3	8,208	283	1,578,146
Chlorination	3	2,005	—	—	—	—	20	152,441
Improved operation	11	14,842	15	19,057	9	3,250	270	549,622
Connection to adequate system	2	305	—	—	3	7,899	18	49,838
None	201	505,959	339	528,601	155	433,419	3,229	31,252,438

* Extrapolated on basis of reported needs.

drainage basins are shown in Tables VII and VIII, respectively.

Data in Table VII show rather significantly that the larger cities of the United States are meeting current sewage treatment needs more adequately than the smaller communities. Cities of less than 25,000 population, which comprise over 95 per cent of the sewered communities in the United States, have 35.1 per cent of the connected population and 47.2 per cent of the dollar cost of backlog needs. In those cities of over 100,000 with almost 45 per cent of the sewered population and whose facilities serve over 53 per cent of the total sewered population, the cost of backlog treatment needs is 30.9 per cent of the United States total.

TABLE VI.—Cost of Treatment Backlog

Need	Cost* (millions)
Replacements and new plants	1,399.9
Enlargements	105.2
Additions	216.4
Connection to adequate systems	45.0
Total	1,766.5

* 1957 dollars.

Over 32 per cent of the dollar cost of needs ($571.8 million) are concentrated in the highly populous New England and North Atlantic drainage basins. In the Ohio River basin, $248 million is required to meet the present backlog.

The relationships between needs and sewered population present rather interesting comparisons. Eight of the 15 major basins have percentages of total U. S. costs in excess of their proportion of total U. S. sewered population. In the Missouri, Pacific Northwest, and the Great Basin basins, the cost percentage is more than twice as great as the sewered population percentage. Conversely, the cost percentage is less than one-half the population-sewered percentage in two basins —the Lake Erie and Western Gulf.

Discussion

The $1.8 billion cost to eliminate the backlog of municipal sewage treatment needs represents only a portion of what must be spent to conserve the quality of this Nation's waters. The recent "Rockefeller Report" (6) on the national economy gives an estimated

range of expenditures for water supply and sewage disposal of $2.7 to $3.5 billion in 1967. This is over two to three times as much as was spent in 1957. While expenditures for new sewage treatment plant construction have shown a decided annual increase in recent years, the rate of expenditure must increase still more sharply in order to make inroads on the large volume of immediate needs and still keep pace with the new needs of a rapidly increasing population.

The municipal sewage treatment needs as reported in the "Inventory" and summarized and quantified in this paper are based on historic, conventional parameters of pollution. The needs, if any, that may develop as a result of more accurate characterization of some of the newer wastes entering community sewer systems, are conjectural. However, in view of the burgeoning use of these products, both in the home and in industry, it can be assumed that the needs will be substantial. Rapidly developing uses of atomic energy for peaceful purposes may also contribute significant radioactive pollution unless adequate preventive measures are taken.

TABLE VII.—Cost of Treatment Backlog by Population Groups

Population Group	Cost* (millions)	Per Cent of Total
Under 500	9.6	0.6
500–1,000	38.9	2.2
1,000–5,000	294.0	16.6
5,000–10,000	179.1	10.1
10,000–25,000	312.4	17.7
25,000–50,000	189.1	10.7
50,000–100,000	198.3	11.2
Over 100,000	545.1	30.9
Total	1,766.5	100.0

* 1957 dollars.

TABLE VIII.—Cost of Treatment Backlog by Drainage Basins

Drainage Basin	Cost* (millions)	Per Cent of Total
Northeast	312.8	17.7
North Atlantic	259.0	14.7
Southeast	121.5	6.9
Tennessee River	32.5	1.8
Ohio River	248.0	14.0
Lake Erie	24.9	1.4
Upper Mississippi	132.5	7.5
Western Great Lakes	104.6	5.9
Missouri River	169.0	9.6
Southwest-Lower Mississippi	84.6	4.8
Colorado River	12.4	0.7
Western Gulf	26.1	1.5
Pacific Northwest	107.5	6.1
California	99.1	5.6
Great Basin	32.0	1.8
Total	1,766.5	100.0

* 1957 dollars.

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METHODS FOR MEASURING GREASE IN SEWAGE

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Two methods for the determination of grease in sewage appear in "Standard Methods" (1), the Soxhlet extraction method and the tentative semi-wet extraction method. In their development of these techniques, Gilcreas, Sanderson, and Elmer (2) showed that the Soxhlet extraction method is more accurate and precise than the semi-wet procedure. Some unanswered questions remained.

Reclamation of solvent for reuse in the Soxhlet extraction method is desirable as the solvent must be distilled during the procedure. However, since petroleum ether is a mixture of hydrocarbons having various boiling points, distillation may result in loss of low-boiling fractions, with a resulting change in composition affecting the rate of solution of different greases. In the development of the Soxhlet method, several solvents were investigated (3). Petroleum ether was selected as the most desirable on the criteria that the material extracted contained the least amount of ash and Kjeldahl nitrogen. Since 1947 when the original work was started, normal hexane has become commercially available. This solvent has a definite composition and boiling point and is not changed by distillation. Normal hexane is the chief constituent of petroleum ether, and the solvent characteristics of the two should be similar. Therefore, it seemed desirable to investigate the effect of substituting *n*-hexane for petroleum ether in the Soxhlet procedure.

The initial work of Gilcreas and associates was confined to the determination of grease in domestic sewage and in samples to which a standard grease had been added. No data were obtained on the precision and accuracy of the method when moderate and large amounts of petroleum oil were present. As petroleum products are frequently encountered in industrial wastes and to some extent in domestic sewage, information on the suitability of the Soxhlet extraction procedure for their measurement would be useful. Studies of the limiting amounts of petroleum oil which could be determined accurately and precisely by the method and of possible modifications are included in this investigation.

In the determination of grease, an absolute quantity of a specific substance is not measured. Rather, groups of substances with similar physical characteristics are determined quantitatively, based upon their mutual solubility in the solvent used. Grease therefore can be said to include fats, waxes, oils, and any other material extracted by petroleum ether from an acidified sample of sewage which would not be volatilized during the procedure used. The deleterious effect these materials have on sewage treatment plant operation and digestion processes as well as the offensive appearance they present on water surfaces is well known. Correction of such conditions would be much simpler if some means were available for distinguishing between petroleum and nonpetroleum products in grease. For this reason an attempt was made to establish a method for the separation and subsequent determination of each

of these two constituents in the material obtained by the Soxhlet extraction method.

To simplify terminology, the following definitions are used.

1. Grease—that material determined by the Soxhlet extraction method.
2. Hydrocarbon—that portion of the grease of petroleum origin.
3. Fatty matter—that portion of the grease of animal or vegetable origin.

The investigation was undertaken in four sections: (a) the development of a method for the differentiation between grease of petroleum and nonpetroleum origin; (b) the evaluation of *n*-hexane as a solvent; (c) experimental work on sewage to which oil had been added; and (d) precision and accuracy studies of the method using *n*-hexane as a solvent.

To test the procedures on as wide a variety of sewage as possible, samples were taken from five local treatment plants. The oil used in all cases was Shell SAE 20.

Experimental Results

Petroleum and Nonpetroleum Fractions

The following criteria were used for evaluation of methods for the differentiation between grease of petroleum and nonpetroleum origin:

1. Reproducibility (minimum standard deviation in replicate determinations).
2. Minimum time required to complete a determination, including both elapsed and personnel time.
3. Absence of special techniques or apparatus.

The previously mentioned definition of grease—any material extracted from sewage by an individual method—is obviously an arbitrary one. Development of a procedure to distinguish between grease of petroleum and nonpetroleum origin is also somewhat arbitrary in that it must be based on particular chemical or physical characteristics peculiar to the majority of the constituents classified as being of either petroleum or nonpetroleum origin.

Three techniques were considered: (a) fluorimetry, (b) ultraviolet absorption, and (c) chromatographic adsorption. The first two are similar in that both depend on the absorption of ultraviolet light by certain constituents of the oil. In the fluorimetric method the emission of light from molecules which have been activated by absorbed ultraviolet radiation provides the means of identification and measurement. The ultraviolet absorption technique utilizes directly the amount of absorbed radiation as a measure of the absorbing material. Although both of these methods are simple to carry out, and both exhibit a fair degree of reproducibility, the specialized equipment required imposes a serious limitation on their usefulness and they were abandoned.

A chromatographic separation of the petroleum and nonpetroleum fractions, based upon the fact that petroleum is composed mainly of nonpolar hydrocarbons while animal and vegetable fats and oils are polar, seemed to be a possibility. Alumina adsorption columns, 1 cm in diameter and 12 cm high, were used. Petroleum ether solutions of mixtures of Crisco and SAE 20 lubricating oil were passed through the columns and the nonpolar constituents eluted with seven successive 10-ml volumes of petroleum ether. Distillation of the solvent from the material which passed through the column yielded an oily residue. Elution of lubricating oil by this method yielded from 90 to 95 per cent of the original amount added. Theoretically, it should be possible by the selective use of various solvents to isolate the components of the adsorbed material that might be of value in a study of a specific problem. How-

ever, for the development of the test this phase was not pursued.

A maximum column capacity of 700 mg of adsorbed material was found to prevail. After columns had adsorbed about 500 mg of material, new ones were prepared. Grease was completely destroyed and the used alumina reactivated by ignition for five hours at 600°C.

Solvent Comparison

In previous work (2) sewage was homogenized to obtain, as nearly as possible, replicate portions of samples for determination of precision independent of sampling error. However, for the following tests a large sample was stirred in the laboratory for 30 min with a motor-driven propeller, and replicate portions taken for examination. Thus, precision of these tests is affected by sampling error but more nearly approximates analysis of actual samples.

After stirring, portions were siphoned into 2-liter beakers and weighed amounts of oil were added. Four sets of triplicate samples were examined by the Soxhlet extraction method (1) for each of five sewages and using each of the two solvents, petroleum ether and *n*-hexane. The range, *R* (difference between smallest and largest of *n* observations), for the triplicate portions varied from 1.1 to 9.8 mg when petroleum ether was used, and from 0.6 to 10.8 mg when *n*-hexane was used. These values are greater than those obtained for samples to which no oil was added. For these latter samples *R* varied from 1.1 to 7.0 mg with petroleum ether, and from 1.4 to 5.5 mg with *n*-hexane as the solvent. However, with the addition of oil the total amount of extractable material is increased and when ranges are calculated on a percentage basis the presence or absence of oil in the sample is shown to have little effect on the values of *R*.

If the determinations made on each sewage are considered individually, three of the five variance ratios, *F*, are greater than the value for the 5 per cent level of significance (Table I). However, these *F* values are inconsistent in that two sets of results show that petroleum ether yields more precise results while the third set shows *n*-hexane to be the more satisfactory. Undoubtedly sampling errors, caused by the presence of large grease-bearing particles in the samples examined, were the chief reason for these discrepancies. If the data obtained for the five sets of determinations are treated as a unit, the resulting variance ratio, *F*, is less than the value for the 5 per cent level of significance. Since statistical treatment of the whole rather than the parts tends to lessen the effect of random error, more valid comparison is probably obtained by using the over-all variance ratio. These results would then indicate that the substitution of *n*-hexane for petroleum ether does not affect the precision of the method.

To eliminate as much repetition as possible, the extract residues from the previous stage were used to evaluate the alumina separation technique. In each case, the extract was dissolved in 10 ml of petroleum ether or *n*-hexane, depending upon the solvent used in the original extraction. The solution was then passed through an alumina column, the nonpolar constituents eluted with seven successive 10-ml volumes of the solvent, and the eluate collected in a weighed flask. After evaporation of the solvent over a water bath the flask and its contents were dried for 15 min under vacuum over a steam bath, cooled in a desiccator, and reweighed, the difference being the hydrocarbon portion of the original residue. The fatty matter was taken as the difference between the weights of total grease and the hydrocarbon fraction.

The results of this phase of the investigation are also shown in Table I.

TABLE I.—Comparison of *n*-Hexane and Petroleum Ether for the Determination of Grease, Fatty Matter, and Hydrocarbons in Sewage

Determination	Run	Petroleum Ether				*n*-Hexane				Variance Ratio (F-test)		
		Std. Dev. (mg)	Std. Dev. (%)	Range (mg)	Arith. Mean (mg)	Std. Dev. (mg)	Std. Dev. (%)	Range (mg)	Arith. Mean (mg)	F calc.	$F_{5\%}$	$F_{1\%}$
Total grease	1	2.09	2.52	4.0	83.0	4.14	4.92	7.6	84.2	3.92	2.69	4.16
	2	1.78	1.98	3.5	89.6	1.05	1.16	1.8	90.4	2.84	2.69	4.16
	3	2.28	2.64	4.5	86.3	1.98	2.50	3.9	86.8	1.29	2.69	4.16
	4	3.41	2.44	6.6	139.4	3.70	2.85	6.9	142.9	1.18	2.69	4.16
	5	1.29	1.57	2.5	82.2	2.45	2.90	4.6	84.6	3.89	2.69	4.16
Avg	—	2.18	2.26	4.3	96.2	2.70	2.76	4.8	97.8	1.49*	1.53*	1.84*
Hydrocarbons	1	3.72	5.37	5.3	69.2	3.87	5.21	5.5	74.3	1.07	3.44	6.03
	2	1.62	2.20	3.1	73.6	2.46	3.30	4.8	74.6	2.30	2.69	4.16
	3	2.44	3.39	4.8	71.8	2.24	3.09	4.3	72.6	1.18	2.69	4.16
	4	3.12	4.13	5.4	75.6	1.38	1.75	2.5	78.8	5.12	2.69	4.16
	5	0.80	1.07	1.5	74.6	1.27	1.74	2.4	72.9	2.53	2.69	4.16
Avg	—	2.34	3.21	4.0	73.0	2.24	2.99	3.9	74.8	1.09*	1.53*	1.84*
Fatty matter	1	2.61	18.32	3.7	14.3	2.13	22.72	3.3	9.4	1.50	3.44	6.03
	2	2.14	13.31	4.2	16.1	2.32	14.60	4.4	15.8	1.18	2.69	4.16
	3	2.21	15.21	4.3	14.5	2.99	21.22	5.8	14.1	1.85	2.69	4.16
	4	4.74	7.43	9.3	63.8	3.70	4.38	7.0	64.5	1.65	2.69	4.16
	5	1.55	20.38	3.0	7.6	2.86	24.42	5.3	11.7	3.40	2.69	4.16
Avg	—	2.43	14.41	4.9	23.3	2.80	12.12	5.2	23.1	1.12*	1.53*	1.84*

* Computation based on combined data from Runs 1 through 5.

As in the preceding work, random errors caused by poor grease distribution in the sewage seem to cause discrepancies in the individual variance ratios. Again, the calculation of a variance ratio using data from all five sets of determinations eliminates the effect of these random errors. Therefore, the two solvents, petroleum ether and *n*-hexane, can be interchanged in the separation technique also, without effect upon the precision of the method. The results also indicate that any loss of total grease is evenly distributed between the fatty matter and hydrocarbon portions, giving further evidence that the precision of the Soxhlet extraction method is unaffected by the presence of petroleum oil in the sample.

Oil-Sewage Mixture

To obtain information about the limiting amount of grease that could be determined with accuracy and precision and to study the effect of increasing the amount of filter aid used, two sets of triplicate samples were prepared by adding 100-, 200-, and 400-mg portions of oil to 1-liter volumes of sewage. The two sets of samples were then analyzed, employing 1 and 2 g of filter aid, respectively, for the filtrations. The sewage used at this time had an extremely high grease content which exceeded the capacity of the alumina column for separating hydrocarbon and fatty matter, although it offered no difficulty in the total grease determination. Therefore, the work was repeated with sewage of lower grease content. The extracted grease was redissolved and separated by the alumina column technique.

Figure 1 shows the relationship between the amount of oil added and the amount of grease, hydrocarbon, and fatty matter recovered. In all cases,

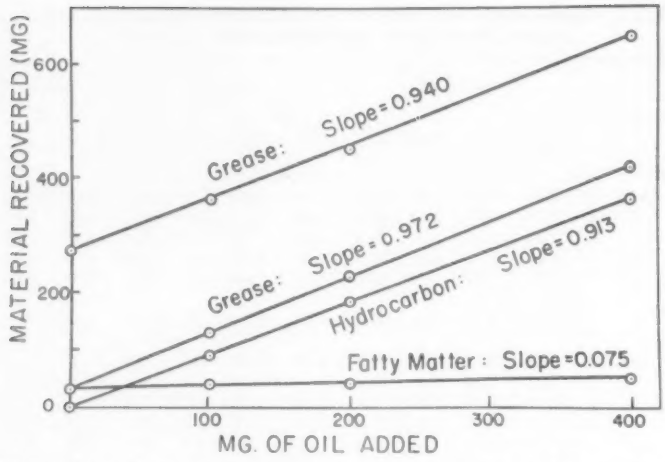

FIGURE 1.—Effect of oil and grease concentrations on recovery of grease, hydrocarbon, and fatty matter.

practically identical results were obtained with 1 and with 2 g of filter aid. Thus, the use of 2 g of filter aid did not improve the accuracy or precision. The straight-line relationships between oil added and grease, hydrocarbon, and fatty matter recovered indicate that the accuracy is not decreased by the presence in the sample of as much as 400 mg of oil in a mixture having a grease content of as much as 650 mg. Comparison of the standard deviations of the four sets of data shows the variance ratios to be well below the value for the 5 per cent level of significance and the precision to be independent of the amount of oil or grease present in the samples within the ranges studied.

Precision and Accuracy for n-Hexane

These studies consisted of two phases; first, an estimate of precision using a domestic sewage, and second, an accuracy study of synthetic samples containing known amounts of Shell SAE 20 oil and Crisco.

In the first part, 10 replicate determinations were made on each of two settled sewages. The amount of total grease was determined using the Soxhlet extraction method with *n*-hexane as the solvent, and next the fatty matter and hydrocarbon portions were determined. The results are shown in Table II. Standard deviations are lower than the 1.5 value reported in the original work of Gilcreas *et al.* (2) in which petroleum

TABLE II.—Precision of Proposed Methods using *n*-Hexane

Statistical Parameter	Settled Sewage—A			Settled Sewage—B		
	Total Grease	Hydrocarbon	Fatty Matter	Total Grease	Hydrocarbon	Fatty Matter
Arith. mean, $\bar{x}$ (mg)	16.0	1.4	14.6	19.4	2.5	16.9
Range, R (mg)	2.5	0.6	2.4	1.4	2.8	3.6
No. of observations, n	10	10	10	10	10	10
Std. deviation, σ (mg)	0.76	0.26	0.81	0.48	1.06	1.23
95% Confidence limit (mg)	$\bar{x}\pm0.54$	$\bar{x}\pm0.19$	$\bar{x}\pm0.58$	$\bar{x}\pm0.34$	$\bar{x}\pm0.75$	$\bar{x}\pm0.88$

TABLE III.—Accuracy of Proposed Methods

Sample No.	Grease Added			Grease Recovered*					
	Oil (mg)	Crisco (mg)	Total (mg)	Oil (mg)	Oil (%)	Crisco (mg)	Crisco (%)†	Total (mg)	Total (%)†
1	0.0	150.0	150.0	2.2	—	149.9	99.7	152.1	101.3
2	0.0	150.0	150.0	2.8	—	151.0	100.7	153.8	103.2
3	0.0	150.0	150.0	2.5	—	150.2	100.2	152.7	101.6
4	44.3	100.0	144.3	39.9	90.2	102.6	102.6	142.5	98.7
5	69.5	100.0	169.5	60.4	86.9	104.4	104.4	164.8	97.2
6	52.0	100.0	152.0	48.7	93.9	100.4	100.4	149.1	98.2
7	96.0	50.0	146.0	88.8	92.5	52.7	105.6	141.5	97.0
8	98.8	50.0	148.8	91.6	92.8	53.2	106.3	144.8	97.3
9	107.4	50.0	157.4	97.4	90.6	55.8	111.6	153.2	97.3
10	171.3	0.0	171.3	154.6	90.2	14.4	—	169.0	98.7
11	153.1	0.0	153.1	138.6	90.3	11.4	—	150.0	98.0
12	162.8	0.0	162.8	144.0	88.4	13.3	—	157.3	96.8
13	102.1	100.0	202.1	94.2	92.1	104.5	104.5	198.7	98.3
14	100.0	100.0	200.0	96.8	96.8	105.2	105.2	202.0	101.0
15	100.3	100.0	200.3	96.1	96.0	101.9	101.9	198.0	98.7
16	197.2	200.0	397.2	179.9	91.2	209.2	104.6	389.1	97.7
17	203.0	200.0	403.0	183.3	91.3	210.2	105.1	393.5	97.6
18	202.8	200.0	402.8	180.9	89.0	211.8	105.9	392.7	97.7
Avg	—	—	—	—	91.5	—	103.9	—	98.7

* Statistical parameters:
Std. dev., σ (oil) = 2.68 mg (2.93%); range, R (oil) = 9.9%.
Std. dev., σ (Crisco) = 3.11 mg (2.96%); range, R (Crisco) = 11.9%.
Std. dev., σ (tot. grease) = 1.84 mg (1.86%); range, R (Crisco) = 6.4%.

† $\frac{\text{Grease recovered}}{\text{Grease added}} \times 100$.

ether was the solvent. This does not necessarily mean that better precision is obtained with *n*-hexane, but it at least illustrates that the substitution of *n*-hexane for petroleum ether can be made without decreasing precision. The values obtained for the standard deviations in the separation of the total grease into fatty matter and hydrocarbon portions are also quite low, indicating that good reproducibility can be secured by the adsorption technique. Table II also shows that the 95 per cent confidence limits are low in both cases and are comparable to the 95 per cent confidence limits in the original work.

In the second part of the investigation, 18 samples were prepared by adding known amounts of Crisco and SAE 20 oil to 1-liter portions of distilled water, to determine the accuracy of the Soxhlet extraction method using *n*-hexane as the solvent and the alumina adsorption technique. For total grease, the values for per cent recovery range from 96.8 to 103.2, with an average of 98.7. In their work with the Soxhlet procedure using petroleum ether, Gilcreas *et al.* (2) obtained an average per cent recovery of 98.2 with a range of 6.0. The similarity between the results when *n*-hexane is used and when petroleum ether is used indicates that interchange of the two solvents does not affect the accuracy of the method.

Table III also shows that the average per cent recovery of oil is only 91.5. Since oil is a mixture of many compounds, this is not surprising. The United States Bureau of Standards states that lubricating oils contain from 18 to 26 per cent straight and branched chain paraffins, 43 to 51 per cent alkylated napthenes (1, 2,

and 3 rings), 23 per cent aromatic hydrocarbons (2, 3, and 4 rings), and 8 per cent asphaltic substances largely aromatic (4). They state as well that the fluorescence of oil is due to the aromatic constituents. Neuworth (5) separated the products of the hydrogenation of coal into three main groups by adsorption on alumina. The least adsorbed were the paraffins, napthalenes, and aromatic hydrocarbons of low molecular weight. The second group consisted of aromatic hydrocarbons containing three or more rings, and the most easily adsorbed were the sulfur, oxygen, and nitrogen compounds. While this has little bearing on this study, it does illustrate the variation in alumina adsorbability of the different constituents of lubricating oil and leads to the conclusion that some of the constituents are not eluted by *n*-hexane. This is further substantiated by the fact that much of the fluorescence of the oil and all of the color are removed by the column. After the passage of oil through the column, the column also exhibits two fluorescent bands as well as one visible band.

Since the adsorbed portion could not readily be eluted from the column, the values for fatty matter as shown in Table III were calculated as the difference between the values for total grease and the hydrocarbon portion. Therefore, the per cent recoveries, when based upon the amount of Crisco added, are all high. Since it is directly dependent upon the precision of the values obtained for total grease and the hydrocarbon portion, precision is correspondingly good.

Discussion

Before any interpretation can be made of the results obtained by the methods described, a clear understanding of what they determine is necessary. Also, suitable terminology must be applied to make the results meaningful to the analyst.

The Soxhlet extraction method will determine hydrocarbon-soluble material of low volatility, including fatty acids of animal and vegetable origin and their esters, as well as hydrocarbons mainly of petroleum origin. The method does not determine the volatile paraffins of C_8 or lower, the cycloparaffins of C_8 or lower, the aromatic hydrocarbon, benzene, or many of the hydrocarbon derivatives of chlorine, sulfur, or nitrogen. Most of the hydrocarbons not determined by the method are lost because of their high volatility in the drying of the thimble, the distillation of the solvent, and the drying of the flask and extracted material. However, these highly volatile compounds would be lost rapidly to the atmosphere in a treatment plant or a stream and would have little sanitary significance except perhaps in cases of ground water pollution.

The separation procedure divides the extract from the Soxhlet extraction method into an alumina-adsorbed portion and a portion not adsorbed by alumina. This separation is brought about, for the most part, by the polarity or lack of polarity of the constituents of the extracted material. It would not be correct to say that the separation isolates all of the nonpolar from the polar material, mainly because adsorption or nonadsorption of a substance depends to some extent upon the degree of polarity rather than upon its presence or complete absence. Therefore, the unadsorbed portion of the extracted material may contain some compounds that are polar, but to a lesser extent than the adsorbed material. However, the unadsorbed portion is composed primarily of the nonpolar or slightly polar hydrocarbons while the adsorbed portion contains, for the most part, fatty acids and their esters as well as some of the more polar hydrocarbons such as complex aromatic compounds and the hydrocarbon

derivatives of chlorine, sulfur, and nitrogen.

In the Soxhlet extraction method, the material determined is called grease. The separation procedure then separates the grease into two portions. This technique was developed to distinguish between products of petroleum and nonpetroleum origin in the grease. The results of the accuracy study (Table III) indicate that an average of only 91.5 per cent of the oil added was recovered. The average per cent recovery of the Soxhlet extraction method is 98.7. Therefore, it is assumed that 1.3 per cent of the oil was lost in the initial extraction and that an average of 7.2 per cent of the oil was adsorbed by the column. This is illustrated by Figure 1. The curve for fatty matter recovery has a slope of 0.075. The value for the slope must represent polar material contributed by the oil. This accounts for the slope of the curve representing the hydrocarbon fraction being only 0.913 as compared with 0.972 for the slope of the curve for grease. This being the case, it would not be completely correct to call the material recovered oil or petroleum unless a correction factor were used. Since it is not certain that the same percentage of all oils is adsorbed by alumina, the use of a correction factor does not seem advisable. Perhaps the most accurate way to define the two components of grease would be as an alumina-adsorbed portion and an alumina-unadsorbed portion. These terms convey little meaning by themselves. Petroleum consists in the main of hydrocarbons associated with small portions of asphalt and compounds containing oxygen, nitrogen, and sulfur. Most of the hydrocarbons are recovered in the eluate after passage of the extract through an alumina column. The asphalt as well as the compounds of nitrogen, chlorine, and sulfur are adsorbed by the column. Therefore, the most appropriate term for the material recovered after the separation is "hydrocarbon." It should be kept in mind that these hydrocarbons are mostly of petroleum origin.

The adsorbed portions are composed mainly of fatty acids and esters as well as any asphaltic material and nitrogen, chlorine, and sulfur derivatives of hydrocarbons that may be present in the extract. Again, selection of a term is necessary to describe, if not all, at least the larger share of those materials adsorbed. Table III shows that the average per cent recovery for the adsorbed portion is 103.9. This value indicates that a portion of the added petroleum is adsorbed. However, since the major portion of the adsorbed material is composed of fatty acids and esters, the most appropriate term for the adsorbed portion is "fatty matter." Therefore, the word "grease" describes that material recovered in the Soxhlet extraction method and the terms "hydrocarbon" and "fatty matter" describe the eluted portion and the adsorbed portion, respectively, in the alumina-adsorption technique.

Summary

An investigation of the Soxhlet extraction method for the determination of grease in sewage was conducted to determine the effect on precision and accuracy of the substitution of *n*-hexane for petroleum ether as the solvent. This substitution would permit the reclamation and reuse of the solvent. Comparison of the two solvents was made by determining the grease content of duplicate sets of sewage samples to which oil had been added. A standard grease composed of Crisco and Shell SAE 20 was used to determine the accuracy and precision of the method using *n*-hexane as the solvent. These values compared favorably with the values obtained in the earlier study (2) in which petroleum ether was the solvent.

In the original work (2), no infor-

mation was secured on the precision and accuracy of the method for the examination of samples containing moderate to high amounts of petroleum products. For this reason, petroleum oil was added to the majority of the sewage samples analyzed in this investigation as well as to the standard grease used in the precision and accuracy determinations. The results indicate that the precision and accuracy of the method are independent of the amount of oil present in the samples.

One hundred and fifty milligrams of total grease was previously found to be the limiting quantity that could be accurately and precisely determined by the Soxhlet extraction procedure. During the course of the present investigation, information obtained indicated that this limiting value might be too low. Consequently, tests were made to determine the validity of this limiting value. The results indicate that as much as 650 mg of grease can be present in the samples without decreasing the precision or accuracy of the method.

Three possible methods were investigated in an attempt to develop a procedure that would enable the analyst to distinguish quantitatively between petroleum products and fatty matter in grease. The method finally selected utilizes a chromatographic separation of polar and nonpolar constituents. This was possible as oil is composed primarily of nonpolar hydrocarbons, while fats are all highly polar. The method meets all three criteria listed earlier: an elapsed time, in addition to the time required to complete the total grease determination, of only one and a half hours, and a personnel time of a half hour; it has a satisfactory precision and accuracy; and specialized equipment or techniques are not needed.

Conclusions

1. A standard deviation of 1.84 mg and an accuracy of 98.7 per cent were obtained for the standard Soxhlet method using *n*-hexane as the solvent, based on the examination of 18 samples containing a combined weight of from 150 to 400 mg of Crisco and SAE 20 oil. These values compare favorably with those reported by Gilcreas *et al.* (2). In that study petroleum ether was used as a solvent and on the basis of a 100-mg sample of standard grease a standard deviation of 1.55 mg and a recovery of 98.2 per cent were obtained.

2. Normal hexane can replace petroleum ether as the solvent in the Soxhlet extraction method with no significant loss in accuracy or precision.

3. The precision of the method is unaffected by the presence of 400 mg of petroleum oil in the samples examined. The previously set limit of 150 mg of total grease that could be accurately and precisely determined by the method is increased to 650 mg.

4. The alumina adsorption technique for the quantitative determination of hydrocarbons in grease has a standard deviation of 2.68 mg for 18 samples containing from 44.3 to 203.0 mg of oil with a per cent recovery of 91.5. The low per cent recovery is caused by the more polar components of the oil being adsorbed by the alumina. For this reason, "hydrocarbon" is a better term to describe the material recovered by this procedure.

5. The value for the amount of fatty matter present in the total grease is determined as the difference in weights of total grease and hydrocarbons. For the fatty matter determination a standard deviation of 3.11 mg was obtained for 18 samples containing from 50 to 200 mg of Crisco with an average per cent recovery of 103.9. The high per cent recovery was caused by the alumina adsorption of polar material present in the oil. However, since the material adsorbed from grease by alumina is, for the most part, of animal and vegetable origin,

the term "fatty matter" best describes the material measured by the procedure.

Determination of Grease by the Soxhlet Extraction Method Using *n*-Hexane

1. Apparatus and Reagents

Extraction apparatus, Soxhlet.
Vacuum pump or other source of vacuum.
Buchner funnel, 12 cm.
Hydrochloric acid, concentrated.
n-hexane, B.P. 69°C.
Filter paper, Whatman No. 40, 11 cm.
Muslin cloth discs, 11 cm.
Filter aid suspension, 10 g Hyflo Super-Cel (Johns-Manville or equal) per liter distilled water.

2. Procedure

Collect a one-liter volume of sewage in a wide-mouth bottle marked at the one-liter volume. Acidify to pH 1.0. Generally, 3 ml of concentrated HCl is sufficient.

Prepare a filter consisting of a muslin cloth disc overlaid with filter paper. Wet the paper and muslin and press down the edges of the paper. Filter with vacuum 100 ml filter aid suspension through the prepared filter and wash with 1 liter of distilled water. Apply vacuum until no more water passes the filter.

Filter the acidified sample through the prepared filter. Apply vacuum until no more water passes the filter.

Remove the filter paper to a watch glass by means of forceps. Add the material adhering to the edges of the muslin cloth disc. Wipe the sides and bottom of the collecting vessel, the stirring rod, and the Buchner funnel with bits of filter paper soaked in *n*-hexane, taking care to remove all films due to grease and to collect all solid material. Add the bits of filter paper to the filter paper on the watch glass. Roll the filter paper and bits of filter paper and fit them in a paper extraction thimble. Add any remaining bits of material adhering to the watch glass. Wipe the watch glass with a bit of filter paper soaked in *n*-hexane and place in paper extraction thimble.

Dry the thimble with the filter paper in a hot air oven at 103°C for 30 min. Fill the thimble with small glass beads. Weigh extraction flask and extract grease in a Soxhlet apparatus using *n*-hexane at a rate of 20 cycles per hr for 4 hr. Time from first cycle.

Distill the solvent from the extraction flask in a water bath at 85°C. Dry by placing flask on a steam bath and draw air through the flask by means of vacuum applied for 15 min. Cool in desiccator 30 min and weigh.

3. Calculation

$$\text{mg/liter total grease} = \frac{\text{mg increase in weight of flask} \times 1{,}000}{\text{ml of sample}}$$

4. Precision and Accuracy

Using synthetic samples containing various amounts of Crisco and Shell SAE 20 oil, an average per cent recovery of 98.7 was obtained with a standard deviation of 1.86 per cent. Ten replicates of each of two sewages yielded standard deviations of 0.76 mg and 0.48 mg, respectively.

Method for Determining Hydrocarbon and Fatty Matter Content of Grease

1. General Discussion

Grease is defined as that material which is extracted from an acidified sample of sewage by *n*-hexane, B.P. 69°C. This grease contains hydrocarbon-soluble material of low volatility, including fatty acids and esters of animal and vegetable origin, as well as hydrocarbons mainly of petroleum origin.

Activated alumina has the ability to adsorb polar materials. Therefore, when a solution of grease dissolved in *n*-hexane is passed through a column of activated alumina, the grease is adsorbed on the surface of the alumina. Further passage of pure solvent through the column elutes the nonpolar material that has been retained on the column. Since petroleum is composed chiefly of nonpolar hydrocarbons, and fatty acids and esters are highly polar, this procedure effects a separation of these two components. The hydrocarbons and fatty matter are expressed as per cent of the total grease.

2. Apparatus and Reagents

Extraction apparatus.
Vacuum pump or other source of vacuum.
Buchner funnel, 12 cm.
Glass tubing, 1-cm ID.
Hydrochloric acid, concentrated.
n-Hexane, B.P. 69°C.
Filter paper, Whatman No. 40, 11 cm.
Muslin cloth discs, 11 cm.
Filter aid suspension, 10 g Hyflo Super-Cel (Johns-Manville or equal) per liter distilled water.
Adsorption alumina, 80–200 mesh.

3. Preparation of Adsorption Column

Draw out over a flame one end of a piece of glass tubing 1 cm ID by 30 cm to an opening of 1 mm diameter. Pack drawn end of tube with glass wool to a depth of 4 cm. Fill tube with adsorption alumina to an over-all height of 16 cm (12 cm of alumina). Place small plug of glass wool in column on surface of alumina. The alumina in the column is capable of adsorbing about 700 mg of polar material and should be repacked with fresh alumina before this limit has been reached. Used alumina may be reactivated by ignition for 5 hr at 600°C in a muffle furnace.

4. Procedure

Dissolve in 10 ml of *n*-hexane the grease in flask after completion of the Soxhlet extraction procedure and pass through the adsorption column. Collect solvent in a tared flask.

Elute the nonpolar material in the column with seven 10-ml portions of *n*-hexane and collect the eluate in the tared flask. Add each successive portion of *n*-hexane when the level of the preceding portion reaches the top of the alumina in the column.

Distill *n*-hexane from the flask in a water bath at 85°C. Dry by placing flask on a steam bath and draw air through the flask by means of vacuum applied for 15 min.

Cool flask in desiccator 30 min and weigh.

5. Calculations

$$\text{Per cent hydrocarbons} = \frac{\text{mg increase in weight of flask} \times 100}{\text{mg of total grease}}$$

$$\text{Per cent fatty matter} = 100 - \text{per cent of hydrocarbons}$$

6. Precision and Accuracy

For the hydrocarbon determination in synthetic samples containing known amounts of Crisco and SAE 20 motor oil, an average of only 91.5 per cent of the oil was recovered for 18 samples examined with a standard deviation of 2.68. The low per cent recovery is caused by the presence of polar nonhydrocarbon material in the oil. Ten replicates each of two sewages yielded standard deviations of 0.26 and 1.06, respectively.

For the determination of the fatty matter content of the grease, the analysis of 18 samples showed an average per cent recovery of 103.9 with a standard deviation of 3.11. The high results are related to the presence of polar material in the oil added. Ten replicates each of two sewages yielded

standard deviations of 0.81 and 1.23, respectively.

Method for Determining Grease in Sludge

Grease is defined as that material which is extracted from an acidified sample by *n*-hexane, B.P. 69°C.

1. Reagents

Magnesium sulfate monohydrate ($MgSO_4 \cdot H_2O$) prepared by drying overnight a thin layer of $MgSO_4 \cdot 7H_2O$ in an oven at 103°C.

n-Hexane, B.P. 69°C.

Grease-free cotton (nonabsorbent cotton after extraction with *n*-hexane).

2. Procedure

In a 150-ml beaker weigh a sample of wet sludge, 20 g ± 0.5 g, of which the dry solid content is known. Acidify to pH 2.0. Generally 0.3 ml concentrated HCl is sufficient. Add 25 g magnesium sulfate monohydrate. Stir to a smooth paste and spread on the sides of the beaker to facilitate subsequent removal. Allow to stand until solidified, 15 to 30 min. Remove the solids and grind in a porcelain mortar. Add the powder to a paper extraction thimble. Wipe the beaker and mortar with small pieces of filter paper moistened with *n*-hexane and add to thimble. Fill the thimble with small glass beads. Extract in a Soxhlet apparatus using *n*-hexane at a rate of 20 cycles per hour for 4 hr.

If any turbidity or suspended matter is present in the extraction flask, remove by filtering through grease-free cotton into another weighed flask. Rinse flask and cotton with *n*-hexane. Distill *n*-hexane from extraction flask in water at 85°C. Dry by placing on steam bath and drawing air through flask with vacuum for 15 min.

Cool in desiccator 30 min and weigh.

3. Calculations

$$\text{Grease as per cent of dry solids} = \frac{\text{gain in wt. of flask in grams} \times 100}{\text{wt. of wet sample} \times \text{per cent dry solids}}$$

Method for Determining Hydrocarbon and Fatty Matter Content of Grease in Sludge

The hydrocarbon and fatty matter content of grease in sludge is determined in the same manner as the determination of the hydrocarbon content of grease in sewage.

Results are expressed as per cent of the total grease in the sludge.

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OXYGEN DEMAND OF DIGESTED SLUDGE LIQUOR

By Edgar A. Jeffrey and Philip F. Morgan

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Sanitary engineers have long understood that biological oxidation of organic material exerts a nitrogenous oxygen demand in addition to the carbonaceous demand (1). In many wastes this secondary demand is relatively small and often ignored. However, in effluents from anaerobic processes this secondary demand may be exceedingly large and appreciably affect oxygenation studies in receiving waters. This study shows that the nitrification demand of the liquor from digested sludge can be most important and that it results from the oxidation of ammonia and nitrite compounds.

While carrying on a sludge lagoon investigation at the State University of Iowa, BOD determinations were made on the discharge from a laboratory lagoon loaded with digested sludge from heated digesters of the Iowa City and Cedar Rapids sewage treatment plants. The sludge in the laboratory lagoons, applied in layers over a period of time, was supported on a 6-in. layer of sand. The discharge, after filtering through the sand and the previously deposited sludge, was a clear dark amber solution with a COD of 300 to 400 ppm.

BOD Results

Standard Dilution Method

Initially, the 5-day BOD of the lagoon discharge was determined according to procedures described in "Standard Methods" (2). The waste was seeded with effluent from the primary settling tank of the Iowa City sewage treatment plant. The results of a series of 5-day BOD determinations are shown below:

Date of Sample (1957)	5-Day BOD (ppm)
July 26	36
Aug. 16	66
Sept. 7	25
Sept. 29	6

These results seemed low in comparison with the anticipated demand so it was decided to determine the BOD over a period longer than 5 days to see whether there was a lag phase in the carbonaceous demand and to study the effect of nitrification.

Jug Method

A dilution method which Orford *et al.* (3) have referred to as the jug dilution method was used as the most practical means of measuring the high oxygen demands over an extended period of time. The details of the procedure were the same as those proposed by Morgan (4) except that for this study the lagoon discharge was initially seeded and was diluted with about 35 volumes of standard BOD dilution water. Additional dilutions were made during the runs as necessary to maintain an adequate quantity for sampling from the jug. The oxygen demands reported are the gross demands of the seeded discharge liquor less the demands of the seed.

The oxygen demand curve, shown in Figure 1, was determined four months after the laboratory lagoons were initially loaded with sludge. The discharge from the lagoons had a high concentration of ammonia (700 ppm) but no nitrites or nitrates. A nitrogen analysis was not made on the settled

primary effluent that was used as seed, so no quantitative balance can be made on the amount of nitrogen oxidized. Nevertheless, the curve shows quite dramatically the very rapid increase in oxygen demand once nitrification starts, and the relative magnitude of the nitrification demand compared to the 5-day BOD.

The answer to the question of whether or not there is more biologically unstable carbonaceous material than was indicated by the initial 5-day BOD's is suggested by the results shown in Figure 1. During the first 10 days the carbonaceous BOD is in the order of 30 ppm which is similar to the 5-day BOD's determined by the standard dilution technique. After 10 days, the rapid rise in demand can be attributed almost exclusively to nitrogenous material.

Nitrogen balances were made on the next three BOD determinations on the lagoon discharge. The experimental oxygen demand curves are shown in Figure 2. These results were obtained several months after the first run and under somewhat different conditions. During these intervening months the drains from the laboratory lagoons had become seeded with nitrifiers, so nitrites and nitrates were present in the lagoon discharge. Also, instead of primary tank effluent being used as seed, final trickling filter effluent, which contained nitrites and nitrates, was used. The final effluent was used in the hope of reducing the long lag phase before nitrification starts. The earlier rise in the oxygen demand curves in Figure 2, compared with Figure 1, indicates that such a reduction was accomplished.

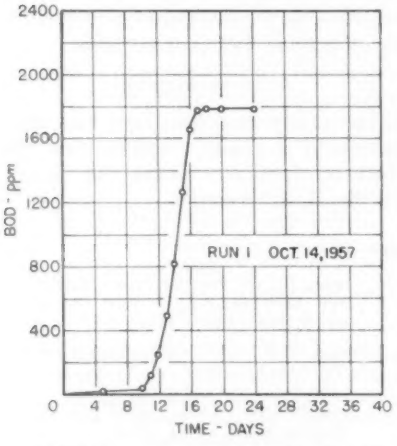

FIGURE 1.—Oxygen demand of sludge lagoon discharge seeded with settled sewage.

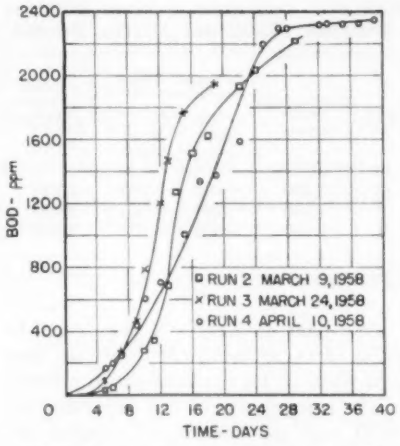

FIGURE 2.—Oxygen demand of sludge lagoon discharge seeded with trickling filter effluent.

Nitrogenous Oxygen Demand

Ammonia, nitrite, nitrate, and organic nitrogen analyses were made on the seed and the lagoon discharge. No organic nitrogen was detected in the plant effluent or the lagoon discharge. The percentage of nitrogen accounted for varied from 98 to 104 per cent of the original nitrogen content. Only the nitrogen attributable to the lagoon discharge was used in computing the nitrogenous oxygen demand. The computation of the oxygen required in the oxidation of the ammonia and nitrites is based on the chemical reactions (1):

$$NH_3 + 1.5\ O_2 = HNO_2 + H_2O$$
$$NH_3 + 2\ O_2 = HNO_3 + H_2O$$

TABLE I.—Comparison of Actual BOD and Computed Nitrogenous Oxygen Demand

Run	Experimental BOD (ppm)	Nitrogen Change During Incubation		Computed Nitrogenous Oxygen Demand (ppm)
		NH_3* (ppm)	NO_3* (ppm)	
2	2,220	−481	−38.9	2,240
3	1,950	−420	−72.2	2,000
4	2,360	−502	−77.8	2,380

* As nitrogen.

One part of $NH_3 - N$ requires 3.43 parts of O_2 to oxidize it to nitrite, and 4.57 parts of O_2 to oxidize it to nitrate.

The comparison of the experimental BOD and the theoretical oxygen demand of the nitrogenous material is shown in Table I.

The computed nitrogenous oxygen demand is within 2.5 per cent of the experimental BOD. This discrepancy is similar to that in the nitrogen balance and indicates that all but a negligible amount of oxygen demand was used in nitrification.

The experimental points deviated from the smooth curves in Figure 2 each time an additional dilution was made. This is most noticeable in Run 4, where dilutions were made on the 10th and 17th days. Smaller deviations in Runs 2 and 3 follow dilutions made on the 11th and 14th days in Run 2 and on the 10th day in Run 3. These dilutions momentarily reduce the rate of oxygen demand, but over a period of several days the rate gradually returns to the original value. These deviations have no effect on the total amount of oxygen used or the validity of the nitrogen balance.

Discussion and Summary

1. Clear liquor drained from digested sewage sludge may have 20-to 40-day oxygen demands of over 2,000 ppm. Over 98 per cent of the demand is exerted by the ammonia and nitrite nitrogen as it is oxidized to the nitrate form. The carbonaceous demand is negligible.

2. The length of the lag period before nitrification starts may be dependent upon the method of seeding. For the waste seeded with primary plant effluent there was an initial lag of 10 days in one study. For the waste seeded with secondary plant effluent, and possibly seeded at its source, the lag is reduced to less than 5 days. The sample seeded with primary effluent may be considered similar to conditions in a river where the diluting water is flowing by. The sample seeded with plant effluent may be considered similar to conditions where the digester is discharged to a lake from which there would be continual reseeding.

3. The 5-day BOD determinations may be meaningless if used to evaluate the oxygen demand of liquor from the anaerobic digestion process.

Acknowledgment

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SURVIVAL OF *SALMONELLA TYPHOSA* DURING ANAEROBIC DIGESTION *

II. THE MECHANISM OF SURVIVAL

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The possibility of increased survival of pathogenic bacteria in short retention period digesters has been one of the major reasons for the slow acceptance of the high-rate digestion process for stabilization of sewage sludges. In preliminary studies (1) it was shown that *S. typhosa* and related enteric bacteria experienced a rapid die-off when a large quantity of these organisms was added to digesters with retention periods varying between 6 and 20 days. *S. typhosa* also experienced a rapid daily die-off, showing no tendency for a build-up in the number surviving after 24 hours' retention, when a continuous daily inoculation of a large number of these organisms was carried out over a long period of time into digesters of 6 and 20 days' retention.

The inability of *S. typhosa* to adapt itself for survival indicated that environmental or biological conditions in anaerobic digesters were unfavorable for the typhoid organism. The major factors which could influence bacterial growth and survival during anaerobic digestion were:

1. Oxidation-reduction potential.
2. Available nutrients.
3. Nature of gases.
4. Presence of antibiotic substances.
5. Presence of bacteriophages.
6. Bacterial competition between species.

The purpose of this paper is to show the effects of these environmental and biological influences on the growth of *S. typhosa* and to present the mechanism involved in the survival of this bacterium in anaerobic digesters.

Study Procedures

Oxidation-Reduction Potential

The oxidation-reduction potential (ORP) of a system is a measure of the relative amounts of material present in the oxidized and reduced states and is determined largely by the metabolic activity of the organisms present in the biological system. In order to relate ORP and the survival of *S. typhosa* the organisms were grown in nutrient broth for 48 hr at 37°C. The emf measured between a platinum electrode submerged in the broth culture and a saturated calomel reference electrode was 400 mv which corresponded to a reducing potential of − 154 mv when corrected to the hydrogen scale. This indicated that the typhoid bacteria could grow well at the low ORP levels of digesters.

Available Nutrients

The survival of *S. typhosa* and other enteric bacteria in anaerobic digesters depends on their ability to utilize the nutrient material present for growth and energy supply. Growth studies were carried out in sterile sludge with pure cultures of *S. typhosa*, *A. aerogenes*, and *E. coli* to determine if they could utilize sludge as a source of food.

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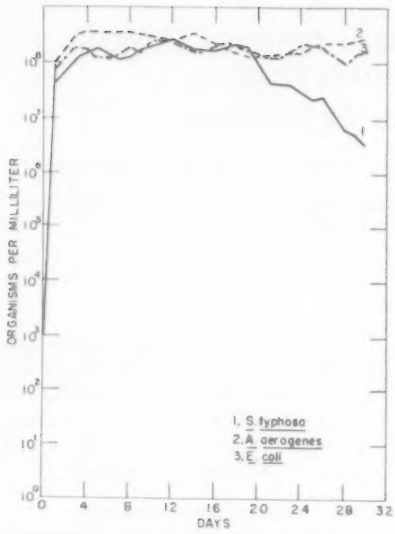

FIGURE 1.—Growth of pure cultures of *Salmonella typhosa*, *Aerobacter aerogenes*, and *Escherichia coli* in individual samples of sterile, buffered raw sludge.

Raw sludge was obtained from the Nut Island Sewage Treatment Plant, Boston, Mass., and homogenized in a blender. Samples were buffered with sodium carbonate and autoclaved at 20 psi for 30 min. Pure culture inoculations of the three test organisms were made into individual samples to provide an initial population of approximately 10^3 bacteria per ml. Samples were stored at 37°C and the growth patterns were followed through daily plate counts using the analytical method previously described (1). Bismuth sulfite (BS) agar was used for typhoid counts, tryptone glucose extract (TGA) agar for *A. aerogenes* counts, and eosin methylene blue (EMB) agar for *E. coli* counts. The results are shown in Figure 1.

Each of the three enteric organisms flourished on sterile sludge with a rapid increase in population to a level of approximately 10^8 bacteria per ml during the first day. Both *A. aerogenes* and *E. coli* maintained population levels above 10^8 per ml throughout the 30-day period of the run. *S. typhosa* maintained a population level above 10^8 per ml through the first 20 days, then decreased slowly to a level of 5×10^6 per ml at the end of the run. This study showed that the three enteric organisms could readily utilize sludge as a food source and could maintain high levels of population in pure culture.

Interrelationship Between Organisms

Many different species of organisms are present in a digester and compete for the available food source. Studies were carried out with mixtures of pure cultures of *S. typhosa* with three bacteria commonly found in sewage sludges, *A. aerogenes*, *E. coli*, and *Ps. fluorescens*, to determine the effects of the interrelationship of these organisms on their growth in sludge. A pure culture of *S. typhosa* and one of each of the other test bacteria were inoculated into sterile, buffered sludge to provide an initial population of approximately 10^3 bacteria per ml for

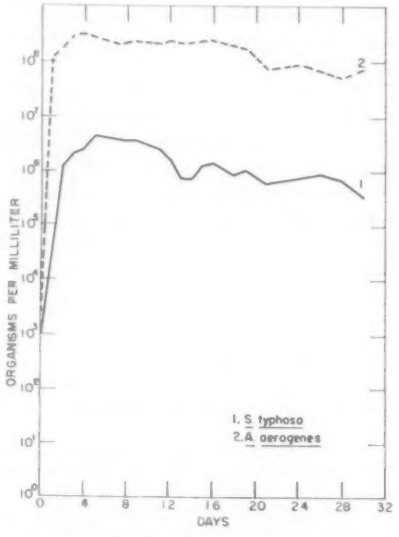

FIGURE 2.—Growth of pure cultures of *Salmonella typhosa* and *Aerobacter aerogenes* in sterile, buffered raw sludge.

each of the two organisms in a sample. Daily counts were obtained to establish the growth patterns of the organisms and are shown in Figures 2 through 4.

A. aerogenes and *E. coli* grew to and maintained populations at about the same levels found for them in pure culture while *S. typhosa* reached population levels only around 5×10^6 per ml in these mixtures and declined to approximately 5×10^5 per ml by the end of the run. *Ps. fluorescens* grew and maintained a population level above 10^8 per ml throughout the run. *S. typhosa* attained a population in this mixture initially near the same level it had in pure culture, but this high initial population declined rapidly to a level of approximately 6×10^5 per ml by the 21st day and remained near this level for the remainder of the run. These results were indicative of bacterial competition for specific food materials.

Gaseous Anaerobic Atmosphere

The anaerobic atmosphere in digesters is composed of several gases

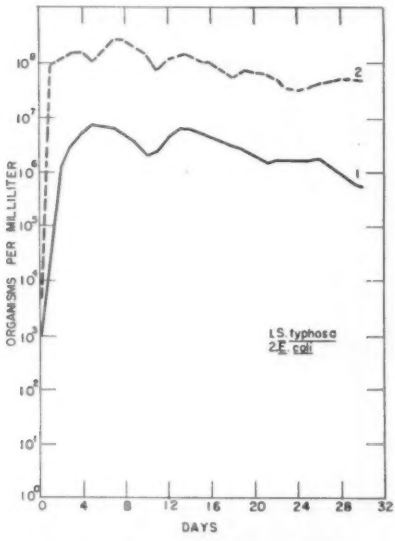

FIGURE 3.—Growth of pure cultures of *Salmonella typhosa* and *Escherichia coli* in sterile, buffered raw sludge.

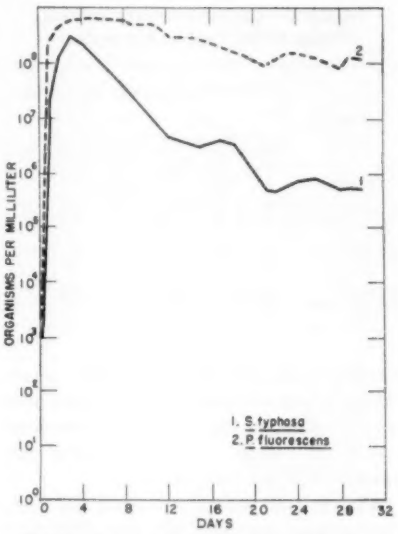

FIGURE 4.—Growth of pure cultures of *Salmonella typhosa* and *Pseudomonas fluorescens* in sterile, buffered raw sludge.

which are not normally present in an aerobic atmosphere. It was postulated that methane gas might act as an enzyme inhibitor in the case of *S. typhosa*. This postulate was based on the theory that enzymes were catalysts of the surface type similar to the metallic surface catalysts used in chemical reactions. Methane might be adsorbed on the enzyme surfaces in the same manner that other gases were adsorbed on the surfaces of metal catalysts, thereby preventing the desired reactions from taking place. Methane was considered as the only major component of digester gas that might act in this manner for carbon dioxide and hydrogen sulfide, as well, were known to be end products of the typhoid organism's metabolism (2) (3). Growth studies with the test organisms in sterile sludge similar to those described previously were carried out with two sets of samples. One set was maintained under a nitrogen atmosphere and the other under a methane atmosphere. The data from these studies are too voluminous to

TABLE I.—Bacterial Growth in Sterile Sludge Under Various Atmospheres

Organism	Population Level (bacteria per ml)		
	Nitrogen Atmosphere	Methane Atmosphere	Air Atmosphere
S. typhosa	2.7×10^7	7.3×10^7	2.1×10^8
S. typhosa	3.5×10^6	7.5×10^6	5.0×10^6
A. aerogenes	1.1×10^8	1.3×10^9	3.8×10^8
S. typhosa	1.3×10^6	3.5×10^6	9.0×10^6
E. coli	1.3×10^8	2.3×10^8	3.0×10^8
S. typhosa	7.8×10^6	1.0×10^7	6.0×10^6
Ps. fluorescens	7.0×10^6	2.1×10^7	7.9×10^6

present here, but the maximum population levels attained by the organisms under nitrogen and methane are compared to those attained under an aerobic atmosphere (Table I).

The initial inoculums provided concentrations between 10^3 and 10^4 bacteria per ml for the organisms in the samples and these populations increased rapidly in 24 hr to near the maximum levels which were attained within the first three days. The populations in all samples declined slowly throughout the remainder of the run, indicating that a gaseous anaerobic environment suppressed the growth of the organisms only slightly. The data did not support the postulated enzyme inhibition by methane gas.

Antibiotics and Bacteriophages

Sewage contains much fecal matter which is a known source of bacteriophages, and several facultative bacteria are known to produce antibiotic substances which inhibit the growth of certain organisms. The presence of either of these antibacterial agents in sewage sludge could specifically limit the growth and survival of *S. typhosa*. Since heat destroys bacteriophages and could possibly alter any antibiotic substances present, the effects of these antibacterial agents would not be apparent from the growth studies in sterile sludge. These antibacterial agents were non-filterable, however, so growth studies similar to those made in sterile sludge were carried out in raw sludge supernatant liquor which had been passed through a bacteriological filter. Two sets of samples were used: (a) plain Seitz-filtered supernatant and (b) heat-sterilized Seitz-filtered supernatant. The initial inoculum population of *S. typhosa* declined in both sets of samples. In mixtures, the other test organisms all grew and maintained population levels at or near the levels they had attained in sterile sewage sludge. The rapid die-off of *S. typhosa* in both sets of samples could possibly have been due to antibiotic substances, bacteriophages, or the lack of food.

Studies on the growth of *S. typhosa* alone were carried out in samples of raw sludge supernatant and primary digester supernatant which had been passed through a bacteriological filter and fortified with nutrient broth. As in the previous studies, one set of samples was plain Seitz-filtered supernatants and the other set was Seitz-filtered supernatants subjected to heat

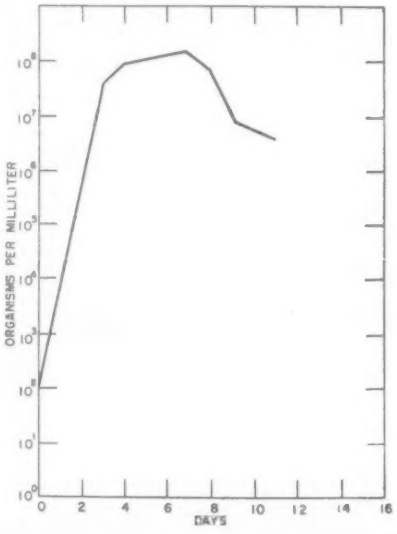

FIGURE 5.—Growth of *Salmonella typhosa* under a methane atmosphere in sterile, resuspended raw sludge solids.

sterilization. *S. typhosa* grew and maintained population levels in all samples equal to the levels it had attained in pure culture in nutrient broth. The results of the supernatant liquor studies showed that die-off of *S. typhosa* was not due to antibiotics or bacteriophages and that the essential food for this organism was not contained in the liquid phase of the sludge.

Bacterial Competition for Food

The previous studies eliminated all of the environmental and biological factors which could have caused the rapid die-off of *S. typhosa* in anaerobic digesters except bacterial competition for food. The existence of such a competition was indicated in the sterile sludge studies. Since supernatant liquor studies showed that the food material in the liquid phase of sludge was not available to the typhoid organism, growth studies were made with samples of sterile, resuspended sludge solids. The samples were prepared by filtering raw sludge, dehydrating the solids, and pulverizing them in a blender. The solids were resuspended in distilled water, sterilized, and inoculated with the test organisms. The growth patterns were obtained by daily plate counts as in previous runs. Examples of the results are shown in Figures 5 through 8 for replicate samples. Other growth studies were made with varying inoculums of the test organisms to determine the effects of initial organism predominance.

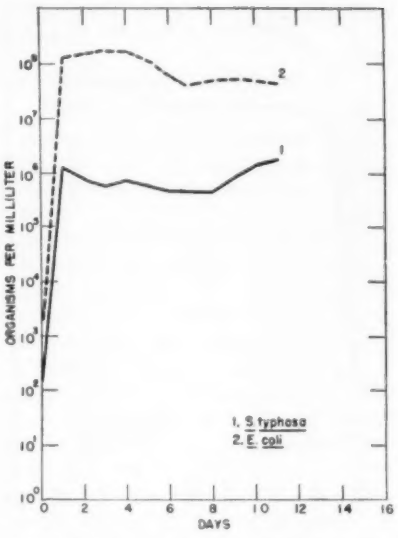

FIGURE 7.—Growth of *Salmonella typhosa* and *Escherichia coli* under a methane atmosphere in sterile, resuspended raw sludge solids.

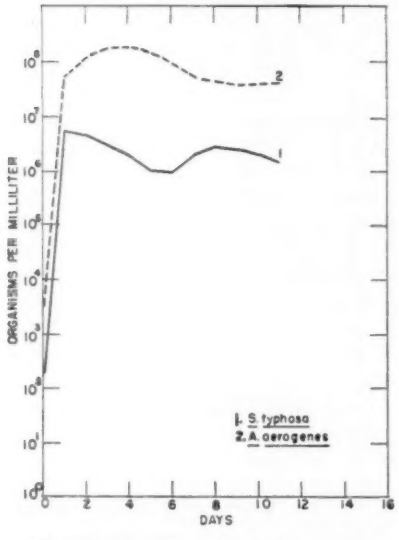

FIGURE 6.—Growth of *Salmonella typhosa* and *Aerobacter aerogenes* under a methane atmosphere in sterile, resuspended raw sludge solids.

The data showed that the typhoid organism could not predominate in the presence of the other test bacteria even when it was initially at equilibrium population at the time a small inoculum of the other test organisms was made into the samples. The other organisms competed more successfully for the food in all instances.

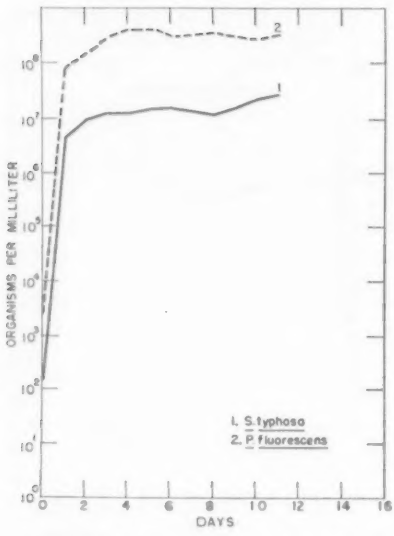

FIGURE 8.—Growth of *Salmonella typhosa* and *Pseudomonas fluorescens* under a methane atmosphere in sterile, resuspended raw sludge solids.

Determination of the Essential Metabolite

The previous studies had all shown that *S. typhosa* was less successful than the other test bacteria in competing for the food material in sludge. The food in the liquid phase of sludge was available to the other test bacteria but not to *S. typhosa*. *S. typhosa* grew only when the solid phase of sludge was present. Thus, it was apparent that there was an essential food element or metabolite in the solid phase of sludge which was required by the typhoid organisms for growth and survival. Studies were made on various fractions of sludge solids in order to identify this essential material.

Ether Extraction

Samples of dried sludge solids were extracted with petroleum ether for 5.5 hr. The petroleum ether was removed by evaporation and the residual material was taken up in tap water buffered at pH 7 with phosphate buffer. The residual sludge solids were resuspended in distilled water. Both samples were sterilized and inoculated with *S. typhosa*. Growth patterns were established by plate counts and the results are shown in Figure 9. The data showed that the essential material was slightly soluble in petroleum ether, but the major portion remained in the ether-insoluble fraction. Therefore, the essential metabolite was not in the fat component of sludge.

Acid and Basic Hydrolysis

Resuspended sludge solids were hydrolyzed by boiling under reflux for 20 hr with 1:1 HCl for acid hydrolysis and with 6N NaOH for basic hydrolysis. Residual solids were filtered off and dried. The filtrates were neutralized with 6N NaOH or 1:1 HCl and the solids produced during neutralization were removed by filtration and dried. The neutral filtrates were put into cellophane membranes and dialyzed for 20 hr with tap water to

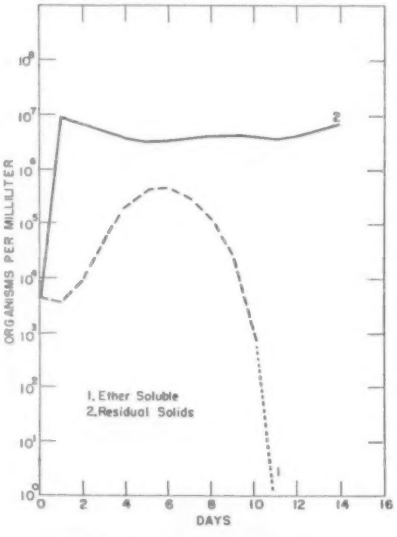

FIGURE 9.—Growth of *Salmonella typhosa* under a methane atmosphere in both fractions of ether-extracted raw sludge solids.

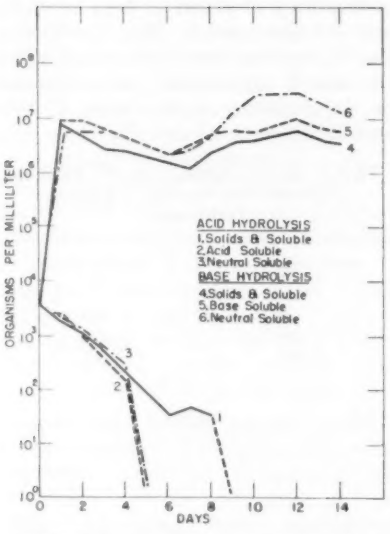

FIGURE 10.—Growth of *Salmonella typhosa* under a methane atmosphere in various fractions of acid and base hydrolyzed raw sludge solids.

remove the salt produced during neutralization. The dialyzed filtrates were evaporated to dryness and then redissolved in distilled water buffered at pH 7 with phosphate buffer. Residual solids were added to some samples to give both acid and base hydrolyzed samples containing all solids and soluble material, acid or base soluble material, and neutral soluble material. After sterilization, the samples were inoculated with *S. typhosa* to give an initial population of 3.4×10^5 bacteria per ml. Daily counts were made and the results are shown in Figure 10.

The initial population of typhoid in the acid hydrolysates declined and died off, but those in the base hydrolysates increased rapidly to a level near 10^7 per ml and remained at or near this level throughout the run. The data showed that the essential material was destroyed by acid hydrolysis. Basic hydrolysis did not destroy the essential material but hydrolyzed it from the complex matter in the sludge solids to a water-soluble compound.

Chromatographic Analysis of Hydrolysates

The neutral soluble fractions of both acid and base hydrolysates were analyzed for their amino acid and carbohydrate contents. Paper chromatography was used and the procedures for this method of analysis have been adequately described (4). The results of the amino acid analysis of the hydrolysis products are presented in Table II. The carbohydrate analyses showed glucose present in the acid hydrolysate and not in the base hydrolysate. These studies showed that the essential material was not a carbohydrate. Comparison of the amino acids in both fractions pointed to tryptophan as being the probable key substance.

TABLE II.—Amino Acid Analysis of Hydrolyzed Sludge Solids

Acid Hydrolysate	Base Hydrolysate
alanine	alanine
aspartic acid	aspartic acid
glutamic acid	glutamic acid
glysine	glysine
leucine	leucine
lysine	lysine
methionine	norleucine
norleucine	norvaline
norvaline	ornithine
ornithine	phenylalanine
phenylalanine	serine
proline	threonine
serine	tryptophan
threonine	valine
valine	

Acid Hydrolysates Fortified with Tryptophan and Tyrosine

Since acid hydrolysis destroyed the typhoid organism's essential metabolite, growth studies were carried out in samples of acid hydrolyzed nutrient broth both with and without tryptophan and tyrosine supplementation. The tryptophan and tyrosine additions were made on the basis of that present in the original peptone of the nutrient

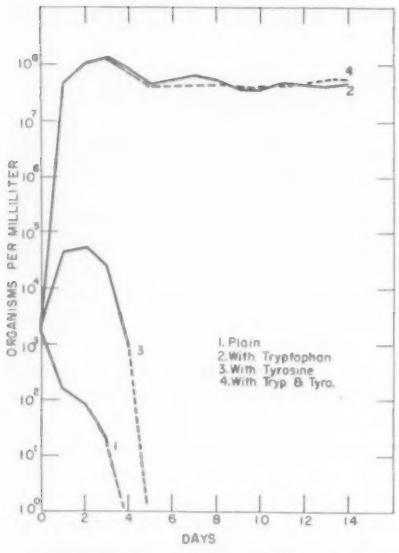

FIGURE 11.—Growth of *Salmonella typhosa* under a methane atmosphere in acid hydrolyzed nutrient broth.

broth. Tyrosine was included in the studies because a positive identification of this amino acid had not been possible in either acid or basic sludge hydrolysis products. The results of these studies are shown in Figure 11.

The data showed that, although *S. typhosa* received some slight growth stimulation initially from tyrosine, a rapid increase to high population levels occurred only when tryptophan was present. Thus, there was no doubt that the amino acid tryptophan was the metabolite in sewage sludge essential to the growth and survival of *S. typhosa*.

Survival in Digesters Fortified with Tryptophan

The final studies to determine the effect of added tryptophan on the survival of *S. typhosa* in anaerobic digesters were carried out in the 20-day digester which has been previously described (1). The runs were made with tryptophan and a large inoculum of typhoid added to the digester. Plate counts were obtained at 2-hr intervals over a 24-hr period. The die-off rates for *S. typhosa* were determined when the added tryptophan concentrations in the digesting sludge were 0, 100, and 1,000 mg/l (Table III).

TABLE III.—*S. Typhosa* Die-Off Rates in Digesters with Varying Tryptophan Enrichment

Added Tryptophan (mg/l)	Die-off Constant (K)
0	4.0
100	2.1
1,000	0.7

These results showed that tryptophan was essential to the survival of *S. typhosa* in anaerobic digesters. Several days after the test runs with tryptophan were completed, there were no typhoid organisms found in the digester. Thus, when a lack of tryptophan available to the typhoid bacteria manifested itself, a decrease in survival resulted.

Discussion

Sewage sludge is potentially an adequate source of food for typhoid bacteria. Under ideal conditions where they are the only species present in the sludge, these organisms can grow and attain levels of population above 10^8 bacteria per ml. This concentration in sludge compares favorably with the concentrations of the organisms grown in a bacteriological medium, nutrient broth. Growth of *S. typhosa*, however, is limited when other common sewage bacteria are present due to the competition between the species for food materials in the sludge.

The pathogen, being more fastidious in its diet, requires an essential metabolite for growth—the amino acid, tryptophan. Tryptophan is an essential component in the protein material of all bacterial protoplasm. Most organisms are capable of synthesizing tryptophan from inorganic nitrogen sources and carbon compounds. *S.*

typhosa is undoubtedly no exception, for it has been shown to synthesize tryptophan from various organic and inorganic nitrogen sources in analytically detectable amounts (5)(6)(7)(8)(9)(10). In the case of typhoid bacteria, however, the amount of tryptophan synthesized is inadequate for growth and the organisms must obtain this essential material from the sources available in the medium.

In anaerobic digesters, many different species of organisms are present, but they can be put into two broad classifications: (a) the methane formers, a group of strict anaerobes, and (b) the acid formers, a group composed mainly of facultative bacteria. The growth and survival of facultative bacteria are essentially the same under both aerobic and anaerobic conditions. A portion of the organic material is utilized for synthesizing bacterial protoplasm and a portion is oxidized for energy. It is in the energy processes that the major difference between aerobic and anaerobic metabolism lies. Anaerobic processes are very wasteful of energy and, therefore, a bacterium must oxidize a relatively larger amount of organic matter to acquire the same amount of energy for metabolism under anaerobic conditions as it does under aerobic conditions.

Under both aerobic and anaerobic conditions, bacterial oxidation is affected by hydrogen transfer. The difference between the two systems is in the material that acts as the hydrogen acceptor. Under aerobic conditions, it is oxygen; while under anaerobic conditions, it is organic material at a lower energy level than the material being oxidized. This process of hydrogen transfer from a material in a higher energy state to a material in a lower energy state provides a net yield of energy to the bacterial cell, but due to the limited amount of material in a digester that can act as the hydrogen acceptor, complete stabilization of organic matter under anaerobic conditions is not possible. Thus, in anaerobic digesters, it is apparent that total organism populations will be lower than under aerobic conditions even though the relative BOD loadings are higher. The bacteria exist in a state of starvation which intensifies with longer retention periods.

S. typhosa belongs to the facultative group of bacteria and is unaffected by the normal conditions of pH, ORP, antibiotics, bacteriophages, or the gaseous environment in digesters. Its survival does depend upon obtaining tryptophan from the sludge, however, and it is this requirement of a specific substance that is the key to *S. typhosa's* limited survival in digesters. *S. typhosa* must obtain tryptophan for growth, but the other facultative bacteria can synthesize this material and as they are at equilibrium population in digesting sludge, they utilize most of the organic matter, including tryptophan, for energy. It is not surprising, therefore, that these other organisms are more successful in the over-all competition, removing available tryptophan and limiting the growth and survival of *S. typhosa*.

The concentration of food in a digester increases with decreasing retention time. Sawyer and Roy (11) have shown that protein destruction is a function of retention time. Destruction of volatile matter at a 6-day detention period was 86 per cent of that occurring in a 20-day digester. This would indicate that the available tryptophan concentration in a digester should increase with decreasing retention time providing for a greater survival of *S. typhosa*. This is no cause for concern, however, because the increased survival would be negligible as the present investigation has shown that extremely high concentrations of available tryptophan are required before there is a significant change in the die-off rate of *S. typhosa*. Even in long retention period digesters some survival can occur. Thus, though the

number of typhoid bacteria surviving in short retention period digesters could be higher, the difference in health hazard between sludges from high-rate and low-rate digesters would be insignificant.

Summary

1. *Salmonella typhosa* grows readily in culture media at ORP levels normally found in anaerobic digesters.

2. Raw sewage sludge is a potentially adequate source of food for *S. typhosa*.

3. *A. aerogenes*, *E. coli*, and *Ps. fluorescens* compete with the typhoid organism for essential food in the sludge and the former are more successful than the typhoid bacteria in the competition.

4. The gaseous anaerobic environment tends to suppress the growth of all the organisms studied, but this is a minor effect in the over-all survival of *S. typhosa*.

5. Bacteriophages and antibiotic substances in the sludge have no effect on the survival of *S. typhosa*.

6. The failure of *S. typhosa* to survive in anaerobic digesters appears to be caused by a limited food supply and a predominance of other organisms which successfully compete against the typhoid bacteria for food.

7. The mechanism of survival of *S. typhosa* in anaerobic sewage treatment processes depends on the organism's ability to acquire the amino acid tryptophan which is essential to its growth and survival under these conditions.

Acknowledgment

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Industrial Wastes

BIOCHEMICAL OXIDATION OF SOME COMMERCIALLY IMPORTANT ORGANIC CYANIDES*

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Accelerated use of organic cyanides (nitriles) for chemical intermediates, synthetic rubber, textiles, plastics, and other products has materially increased the probability of nitrile contamination of surface water. Acrylonitrile has been used more than any of the other nitriles for industrial purposes. Synthetic fibers such as orlon and acrilan, synthetic rubber (either as a major component or modifier), and various acrylic plastics or copolymers account for most of this use. The U. S. Tariff Commission (1) reports acrylonitrile production and sales during 1956 as 140,569,000 lb. This is approximately double the 1947 figure. Moreover, nitriles frequently are produced by a manufacturing unit which uses the material as an intermediate in the synthesis of other products. It is unlikely that this "captive" production will appear in census figures.

Renn (2) investigated the toxicity to fish of lactonitrile, acrylonitrile, and potassium cyanide in aqueous media. He also studied their disappearance in soil samples. His work suggests degradation by biological action. Cherry, Gabaccia, and Senn (3) reported assimilation of acrylonitrile, acrylamide monomer, and oxydipropionitrile in surface water after various periods for acclimatization of the biota. Powers (4) and Stack (5) also report that nitriles are assimilated in biological treatment systems. Trelawney *et al.* (6) isolated organisms capable of metabolizing various organic and inorganic cyanides.

Study Outline

Included in the objectives of this study was the investigation of the behavior pattern of several commercially important organic cyanides. Rate of assimilation, end-products, controlling factors in metabolism, and acclimation were of special interest. Six different nitriles were selected for study. Each had a different radical attached to the cyanide group. They include acetonitrile (CH_3CN), acrylonitrile ($CH_2=CHCN$), adiponitrile ($NC(CH_2)_4CN$), benzonitrile (C_6H_5CN), lactonitrile ($CH_3CHOHCN$), and oxydipropionitrile ($O(C_2H_4CN)_2$). These chemicals cannot be considered as representative of all possible nitriles, but it is believed that the test results should provide certain relations between structure and behavior in water. The data may also suggest probable behavior of similar structures that were not investigated.

All tests were made in Ohio River water obtained from the intake of the Cincinnati waterworks. The water was stored in the dark for at least five days prior to use, to permit sedimentation of algae and silt. Clear supernatant was used for oxidation tests.

Figure 1 is a diagram of the oxidation assembly. A 5-gal oxidation unit was used to minimize individual variations in behavior commonly occurring

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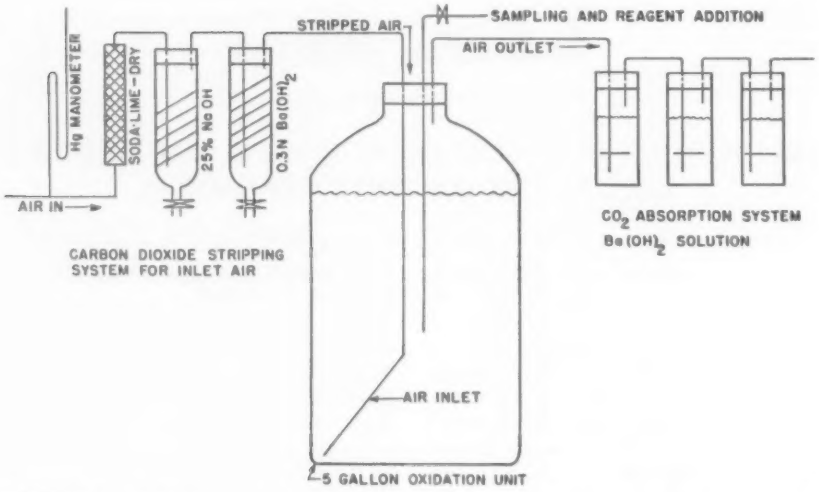

FIGURE 1.—Oxidation system for determining carbon dioxide production from specific organic materials in water.

when small samples of nonhomogeneous material are used as in dilution BOD or Warburg techniques. The larger oxidation unit also made it possible to remove samples for analysis without using a large percentage of substrate. The oxidation bottles were painted black except for a narrow strip for observation of air rate. The system was kept in darkness as much as possible to minimize photosynthesis and concurrent carbon dioxide use.

By appropriate adjustment of air supply and reagent strength, the system was useful for investigation of materials having a low or high oxygen demand. The substrate was sampled only when carbon dioxide production indicated significant change.

Air was fed to the oxidation unit (Figure 1) at approximately 1 bubble per second. This insured aerobic conditions in the oxidation unit unless carbon dioxide production exceeded 300 mg per 24 hr. Entering air was stripped of carbon dioxide in a train consisting of a dry soda lime tube and spiral-flow gas washers containing 25 per cent sodium hydroxide and 0.3 N barium hydroxide, respectively. The last stripper served only as a check on stripping efficiency of the preceding units. If carbon dioxide entered the last unit, barium carbonate precipitated on the inlet port. Detection of such a deposit called for prompt recharge of the train. A mercury manometer on the inlet air line was used to detect obstructions and to adjust air flow between multiple units.

Carbon dioxide production was used as the primary index of activity. Initial and final titrations of excess alkali in the absorbers on the outlet air stream were used for quantitative estimates. Only the first of three units was titrated, except when unusual activity required some of the reserve capacity. When one unit was titrated, the freshly charged absorber was placed last in the line.

The difference in carbon dioxide production between a control and test bottle was assumed to reflect complete oxidation of a part of the added feed. The difference usually was expressed as a percentage of the theoretical carbon dioxide possible after complete

oxidation of the particular applied dosage. Nitrogen analyses (ammonia, organic, nitrate, and nitrite) were made regularly on the nitrile systems and also converted to a percentage of theoretical amounts. The material balance between feed and end products usually was within 10 per cent.

Observation of a specific system was continued until at least 60 per cent of theoretical carbon dioxide was obtained, or until the oxidation curve approached a limit. Shortly after the curve leveled off, 50 per cent of the substrate was removed along with as much of the solids as possible. The portion withdrawn was analyzed for the various forms of nitrogen, alkalinity, pH, extractable components, biological population, and other desired information. The oxidation unit was then recharged with new river water to its original volume of 18 liters. A new feed of the same or different nitrile was then added.

The oxidation unit (Figure 1) was fitted with a tube extending to the center of the substrate. This tube was used for addition of reagents or withdrawal of samples during a run, making it unnecessary to open the bottle and disturb the equilibrium of carbon dioxide in the liquid and gas phases.

Alkalinity tests were used to measure and compare the amount of bound carbon dioxide contained in the control and test samples. A buffer consisting of monobasic potassium phosphate and disodium phosphate was used to control the pH between 6.5 and 7.0. The buffer effectively minimized large variations in alkalinity and enabled the carbon dioxide curve to indicate more nearly activity of the system.

Analytical Methods

No chemical analysis has been found from which it is possible to obtain reliable estimates of the concentration of nitriles in water as a group. Effective analytical methods are known for several individual nitriles, particularly those with unsaturated bonds in the radical attached to the nitrile. Daues and Hamner (7) describe an azeotropic distillation for separation and concentration of acrylonitrile in aqueous samples. Polarographic analysis was effective on the concentrated fraction. Streuli (8) titrated the copolymers of acrylonitrile in nonaqueous solutions. Bird and Hale (9) describe polarographic methods applicable for acrylonitrile. Infrared absorption was used by Kitson and Griffith (10) to characterize nitrile compounds. Quantitative methods in aqueous samples are less attractive using this approach because of losses due to partition coefficients in extraction, reactivity, and volatility of the nitriles. Beesing *et al.* (11) determined acrylonitrile and other unsaturates using dodecanethiol titrations. The cited methods are effective on specific nitriles under the prescribed test conditions. They would be of little value for determination of unknown or mixed nitriles.

Nitrogen analysis frequently has been applied to estimate nitrile concentration of effluents. Table I shows that this approach is not universally effective. The McKenzie and Wallace total Kjeldahl nitrogen method (12) used on fresh nitrile solutions gave results varying from 6 to 100 per cent recovery, depending on the particular nitrile. Volatility and hydrolysis rates apparently govern the fraction recovered.

A modification of the method proposed by Varner *et al.* (13) appeared nearest the desired effectiveness. This method made it possible to obtain high recoveries on five of the six nitriles tested. Varner's method uses ferrous sulfate reduction with a silver catalyst in alkaline solution. The original method was relatively inefficient in converting nitrile nitrogen to recoverable ammonia. By lengthening reduction time to two hours at 65°C, three of the six nitriles tested were reducible to ammonia with a fair yield. Nine-

TABLE I.—Results of Various Analytical Procedures on Fresh Nitrile Solutions

Test	Per Cent of Theoretical					
	Aceto-	Acrylo-	Adipo	Benzo-	Lacto-	Oxydipropio-
Total Kjeldahl nitrogen	<6	<30	95	10	90	>100
Modified reduction	90–100	90–100	95–100	90–100	<20	>100
COD	50–55	80–85	70–75	75–80	45–50	25–30
Azeotropic distillation	70–75	80–90	<4	80–90	<3	<3
Cyanide:						
Direct titr.	Nil	Nil	Nil	Nil	10–15	Nil
Direct color	<1	Trace	Nil	Nil	<10	Nil
After Serfass dist.	<1	Trace	Nil	Nil	10–35	Nil
Activated carbon adsorption	—*	—*	—*	—*	—*	—
Chlorine demand†	—	<5	—	—	10–30	—

* Appeared less than 10 per cent absorption on all nitriles as measured by nitrogen losses in the eluate.

† 15 min.

teen other common metallic catalysts were investigated in an attempt to extend applicability. Silver sulfate and chlorides of nickel, copper, and mercury assisted reduction; 0.2 g of a mixture of equal parts of these salts was used to catalyze reduction. Table I shows that at least 90 per cent of theoretical amounts were obtained on five of the six nitriles tested.

COD results (Table I) showed a recovery of from 25 to 85 per cent. Cyanide tests were of little value, as lactonitrile appeared to be the only one releasing significant cyanide. Yates and Heider (14) found the dissociation constant for lactonitrile to hydrogen cyanide to be 7×10^{-3}; hence, all of the cyanide would dissociate if given suitable conditions and time. Analytical procedures used resulted in recoveries of 10 to 35 per cent of theoretical HCN. Two other nitriles (aceto- and acrylo-) released small yields of HCN from fresh solutions.

Activated carbon adsorption, ion exchange columns, azeotropic distillation, and chlorine demand were of little use as analytical tools for the nitrile group.

Infrared was used to characterize the nitrile stock and to detect significant changes. The appearance of bands different from the reference spectrum was a signal for rejection or purification. Some of the stock nitriles were practical grade reagents; hence, a reference spectrum was obtained on delivery and used for comparison in periodic rechecks. Minor deviations from a reference curve were not considered cause for rejection unless the change became significant on storage. Table I gives one example of an impure starting material (oxydipropionitrile) because nitrogen analysis consistently resulted in more than 100 per cent of theoretical amount in addition to the impurity detectable by infrared. Extractions of oxidized substrates were made to attempt classification of intermediate decomposition products or to detect portions of the original feed. The results were not conclusive because of manipulation losses of the nitriles, but useful information was obtained on certain degradation products.

In view of the failure to obtain methods applicable to the nitrile group in water, primary emphasis was placed on the analysis of degradation products. Carbon dioxide; ammonia, organic, nitrite, and nitrate nitrogen were determined regularly and related to the amount of nitrile and other nutrients in the feed.

BOD tests were made for preliminary evaluation of nitrile oxidizability

TABLE II.—BOD Results on Various Nitriles

Nitrile	No. of Series	Seed	Conc. Range Tested (mg/l)	Conc. for Definite Inhibition at 5 Days (mg/l)	Median Per Cent of Theoretical Oxygen Demand		
					2 days	5 days	12 days
Aceto-	3	—*	0.1 to 25	0.1	Nil	Nil	20
	3	—†	0.1 to 25	3.0	Nil	20	40
Acrylo-	5	—*	0.1 to 20	0.1	Nil	Nil	5
	5	—†	0.1 to 20	0.5	Nil	Nil	15
Adipo-	4	—†	0.5 to 10	—‡	Nil	40	>100
Benzo-	5	—*	0.1 to 15	10	Nil	40	80
	5	—†	0.5 to 20	—‡	Nil	60	90
Lacto-	4	—*	0.4 to 15	—‡	40	60	—
	5	—†	0.4 to 15	—‡	50	70	75
Oxydipropio-	3	—†	0.6 to 12	<0.6	Nil	Nil	5

* Aged sewage.
† Ohio River.
‡ No detectable inhibition at 5 days.

and to determine approximate dosage levels. Each nitrile was set up in several different concentrations using both Ohio River water and stored sewage seed. Residual oxygen was determined at 1, 2, 5, and 12 days. No special acclimatization of the seed was attempted. The median per cent of theoretical oxidation is given in Table II because of variable results. Oxygen depletion less than the control was considered evidence of inhibition and an indication of the toxicity of the particular nitrile to microbiological growth. The theoretical percentage was calculated for carbonaceous oxidation so that appreciable nitrification could result in more than 100 per cent.

Analytical methods other than those specifically cited followed the procedures in "Standard Methods" (15).

Results

The results in Table II show that aceto-, adipo-, benzo- and lactonitrile were amenable to biological degradation. Acrylo- and oxydipropionitrile were more resistant. Nearly all of the nitriles produced lags of at least two days. River water dosed with lactonitrile started oxidation earlier than with other nitriles. Ohio River water contained organisms more capable of nitrile assimilation than those from aged sewage.

The curve shown in Figure 2 represents carbon dioxide production versus time for acetonitrile oxidation in river water. Initial dose of nitrile was 10 mg/l. Relatively little action occurred for the first week, although no definite toxicity was detectable. Thereafter, the curve shows acceleration in carbon dioxide production characteristic of a biota rapidly increasing in suitable population. After addition of the second nitrile dose of 10 mg/l on the 21st day, the system required only four days to produce a higher percentage of theoretical carbon dioxide than before. From the 25th to 36th day, serial feedings of 20 and 40 mg/l of acetonitrile were assimilated. The oxidation temperature was dropped from 20 to 5°C on the 42nd day, after dosage of 40 mg/l. The rate of assimilation was about 20 per cent of that at the higher temperature. Benzo- and adiponitrile produced curves similar to that shown in Figure 2 for acetonitrile except that assimilation started more rapidly.

Figure 3 shows a similar curve for acrylonitrile. A marked inhibition was noted during the first week of observation. Assimilation during the second week was fairly rapid for a few days, then apparently reached a plateau.

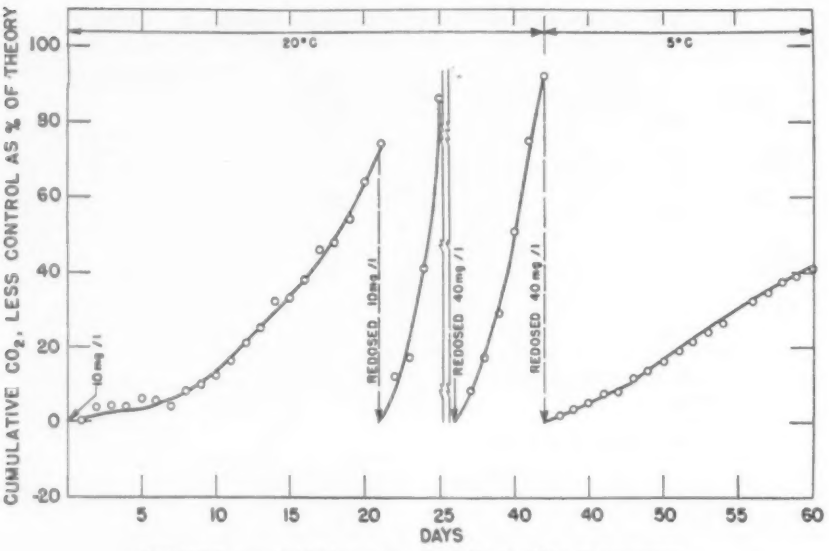

FIGURE 2.—Oxidation of acetonitrile in Ohio River water.

After 10 days of apparent inactivity, metabolism became quite active again. The lag period and plateau effect were not detectable on subsequent serial feedings. The acrylonitrile was more slowly metabolized than acetonitrile in acclimated or unacclimated systems. A change in temperature to 5°C on the

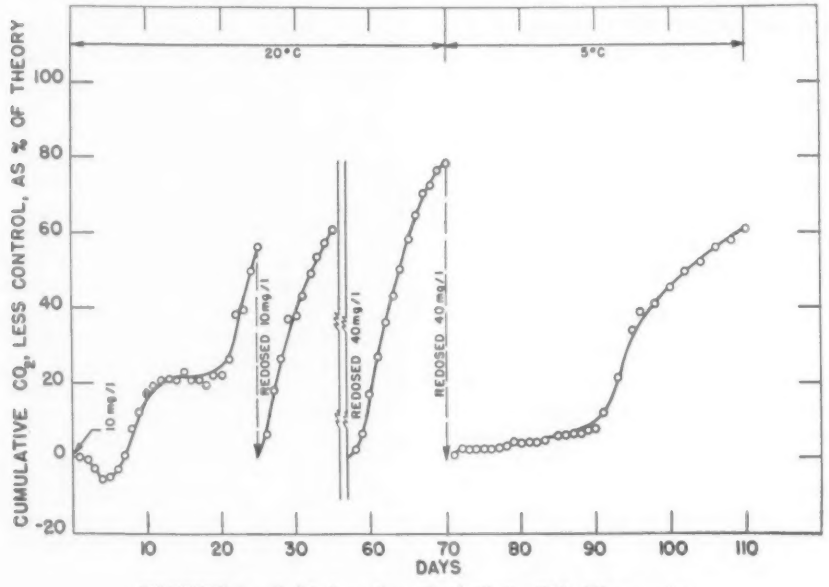

FIGURE 3.—Oxidation of acrylonitrile in Ohio River water.

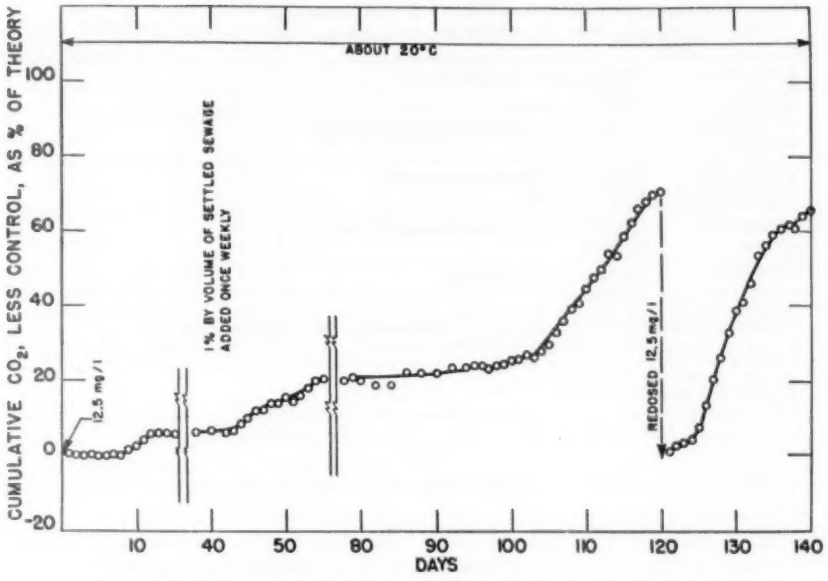

FIGURE 4.—Oxidation of oxydipropionitrile in Ohio River water.

70th day resulted in a marked reduction in assimilation. Lactonitrile oxidations were similar to those for acrylonitrile except that they started more rapidly. The same type of plateau developed on the first feeding and the systems were more unstable.

Figure 4 is a summary of the oxidation results for oxydipropionitrile in river water. There was apparent assimilation in the first two weeks, but a plateau developed short of 10 per cent of theoretical carbon dioxide. No further action was evident in 40 days. Another system failed to progress beyond this point in 125 days. Addition of one per cent by volume of settled sewage per week appeared to help oxidation of the oxydipropionitrile Following sewage addition a prompt but slight increase in assimilation was noted, but over 50 days passed before the carbon dioxide production rose appreciably above 20 per cent of the theoretical amount. Once a suitable biota was developed, oxidation proceeded quite rapidly as indicated by Cherry *et al.* (3). Lags were not significant in redosed systems at the same or higher concentrations.

Acclimatization Summary

A summary of the relative effects of acclimatization for the six nitriles is given in Figure 5. Only the first and second serial feedings are represented; subsequent feedings showed significant gains in assimilation on each nitrile as indicated by the ability to oxidize feed concentrations of at least 40 to 50 mg/l in approximately the same time interval. The time to reach 10 per cent of theoretical carbon dioxide is given to show early lag periods; the next 50 per cent of theoretical limits shows the more rapid phase of metabolism. Each nitrile shows a significant acclimatization, as shown by the time ratio required for 60 per cent of theoretical amount on the first and second doses. Acrylo-, adipo-, and lactonitrile required only about half the time on the second dose, aceto- and benzonitrile about one-fifth, and oxydipropionitrile

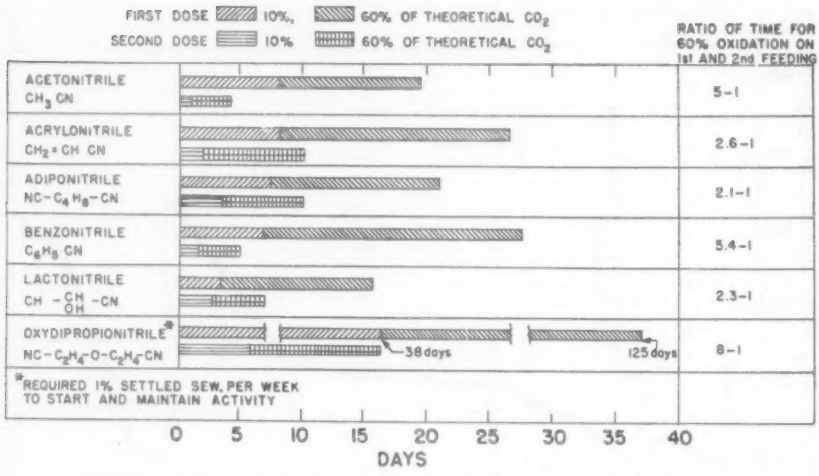

FIGURE 5.—Effect of acclimatization on aerobic decomposition of nitriles.

only about one-eighth of the time for the second as for the first application. Lactonitrile alone indicated an induction period almost as long for the second application as for the first.

Acclimated biological systems for a given nitrile showed ability to oxidize the material regardless of wide variations in dosage. Concentrations of the nitriles tested (5 to 50 mg/l) were metabolized without a significant adjustment period after a concentration change. Aceto-, acrylo-, and lactonitrile-acclimated organisms were able to rest for 30 days after one feed was consumed and start oxidation of a new feed of 40 to 50 mg/l within two days. The new feed was at least 60 per cent oxidized within 10 days.

Temperature Effects

Figure 6 shows the responses of acclimated nitrile systems at 20 and 5°C. Before the temperature change, all

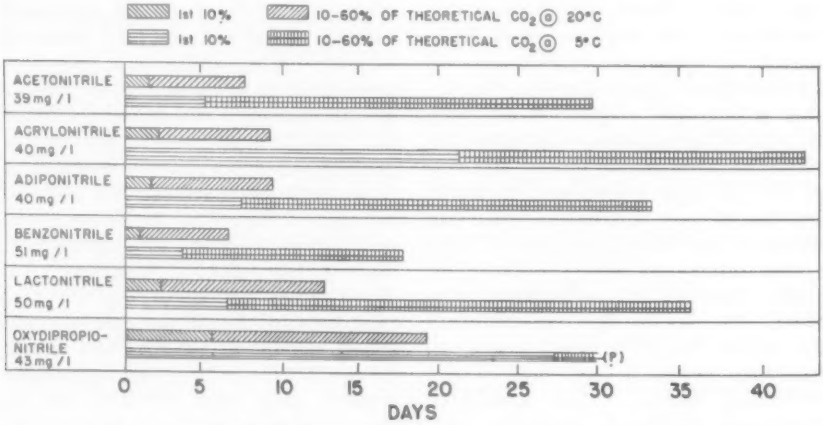
1st 10% 10-60% OF THEORETICAL CO_2 @ 20°C
1st 10% 10-60% OF THEORETICAL CO_2 @ 5°C
ACETONITRILE 39 mg/l
ACRYLONITRILE 40 mg/l
ADIPONITRILE 40 mg/l
BENZONITRILE 51 mg/l
LACTONITRILE 50 mg/l
OXYDIPROPIONITRILE 43 mg/l
(?)
0 5 10 15 20 25 30 35 40
DAYS

FIGURE 6.—Effect of temperature change on acclimated nitrile systems.

TABLE III.—Assimilation Capacity of Acclimated Systems on a Changed Nitrile Feed*

Nitrile Used for Seed Development†	Subsequent Nitrile Feed					
	Aceto-	Adipo-	Benzo-	Acrylo-	Lacto-	Oxydipropio-
Aceto-	—	Yes	—	No	No	No
Adipo-	Yes	—	Yes	—	No	No
Benzo-	Yes	—	—	Yes	No	Questionable
Acrylo-	Yes	No	—	—	Yes	Questionable
Lacto-	Yes	Yes	—	Yes	—	Yes
Oxydipropio-	Yes	Yes	—	Yes	Yes	—

* "Yes" indicates evidence of transfer of acclimatization; "No" indicates little or no evidence of transfer. In general, all except those in the upper right indicate good transfer of assimilative capacity from one nitrile to another.

† Listed in order of increasing seed versatility for oxidation of other nitriles.

systems underwent acclimation by assimilation of two or more feeds of the particular nitrile at the concentration cited. As in Figure 5, the 10 per cent level is included to show adjustment periods, and the next 50 per cent of theoretical carbon dioxide shows the more rapid metabolism. Oxydipropionitrile and acrylonitrile showed the longest induction periods after the temperature change. The next 50 per cent of theoretical CO_2 required about three times as long at 5° as at 20°C. Acetonitrile required a rather short induction period, but took about five times as long at 5° as at 20°C to recover the next 50 per cent of theoretical carbon dioxide. Lacto- and adiponitrile were similar to acrylonitrile except for a relatively short induction period. Benzonitrile appeared least affected by the temperature change both with respect to induction time and the 50 per cent recovery period.

Pronounced acclimation shown in Figure 5 suggested tests to show whether a biota developed on one nitrile would assimilate other nitriles. Table III compares various nitrile assimilations by other nitrile biota and fresh river water biota. Changes reported in Table III were made at 20°C; tests at 5° showed little evidence of transfer of assimilative capacity and were not reported. The left-hand column shows the nitriles on which the seed was developed, listed in the order of increasing seed versatility for oxidation of other nitriles. In general, all combinations except those shown in the upper right show good transfer of assimilative capacity from one nitrile to another. Not all of the possible changes were investigated, but of those tested only one change is out of line. Data on biological variety in the various substrates, discussed later, provide a possible explanation of this.

Nitrogen Data

Acclimated biological systems for a given nitrile converted 60 to 90 per cent of the nitrile nitrogen in the feed to oxidized nitrogen by the time 60 per cent of theoretical carbon dioxide was obtained. In unacclimated systems there was an early increase in ammonia nitrogen which persisted for several days before conversion to nitrite and nitrate nitrogen. Increase in ammonia nitrogen was negligible in solutions of acrylonitrile in tap water after three weeks storage; hence, the hydrolysis of the nitrile apparently was influenced by enzyme action. Refeeding an acclimated biota was not accompanied by a sharp rise in ammonia nitrogen; it was oxidized about as rapidly as it appeared. Established oxidation substrates rarely showed more than 1 mg/l of ammonia nitrogen

in early stages and little or none near the end of oxidation.

Addition of supplementary nitrogen as ammonium chloride made no observable difference in the rate of carbonaceous oxidation since this form was rapidly converted to nitrate. Apparently the nitriles tested provided adequate nitrogen for biological growth.

Total Kjeldahl nitrogen was fairly constant during the oxidation cycle unless the nitrile responded to the total Kjeldahl test in high yield (Table I).

Nitrate concentrations were highly variable depending on the type of nitrile feed, concentration, and stage of oxidation. Nitrites were relatively low except in unacclimated systems where they reached high levels for short periods. They seldom exceeded 0.4 mg/l in established systems.

Cyanide Formation

Lactonitrile oxidations were the only ones showing significant cyanide formation. After a feed, cyanide could be detected in the substrate for about a week. It was trapped in the carbon dioxide absorbers for four to seven days, depending on the lactonitrile feed concentration and degree of acclimatization. The HCN loss by volatilization from the substrates did not exceed 15 per cent of the theoretical amount fed in any test; usually it was much less. Rapid oxidation, as indicated by carbon dioxide production, and nitrification, occurred before the cyanide level dropped, normally by the second or third day.

Infrared Examination

Extractions of well-oxidized substrates did not recover amounts of nitrile detectable by infrared. Trace amounts were occasionally shown during early stages of oxidation, but the curve showed appreciable modification from the reference. Carbonyl absorption appeared in extracts long before carbon dioxide production became significant on new oxydipropionitrile systems. Infrared curves of well-oxidized substrates tended to approach a characteristic form regardless of feed type. This characteristic curve apparently was due to degradation products of metabolic activity.

Biological Observations

Biological observations on nitrile substrates were made primarily for qualitative purposes. Plate counts were made on tryptone glucose agar, and on rose bengal agar, at irregular intervals. Samples could not be mixed adequately to achieve good quantitative results, but significant gains or losses were apparent. Stained slides were prepared occasionally for comparisons.

Most substrates revealed a smaller variety of organisms than untreated river water, but with total plate counts often substantially greater. Hyphae and spores of several different molds were prominent in acrylo-, lacto-, and oxydipropionitrile systems, less common in others. Protozoa were more evident in aceto-, benzo-, and adiponitrile systems but rarely seen in lactonitrile substrates. Cocci and rod-shaped bacteria, usually gram negative, were common to all systems, as were yeast cells. *Trichoderma*, a resistant mold found in soils, was found in lactonitrile systems fed with potassium cyanide. *Pseudomonas aerogenes* and a spore-forming bacillus were numerous in lactonitrile systems and in most of the other active cultures. Lacto- and oxydipropionitrile substrates generally showed a greater variety of organisms, which may explain results in Table III.

Lactonitrile systems were relatively unstable and occasionally showed an almost complete die-out of the population. Cyanide concentrations, nitrogen analyses, alkalinity, and other tests failed to provide an explanation for the die-out. Although lactonitrile usually started metabolism readily, subsequent behavior placed it with the more resistant nitriles.

This die-out should not be confused with the plateau effects found in oxydipropio-, lacto-, and acrylonitrile. The plateaus were associated with carbon dioxide production equivalent to that of the control. Plate counts and slides failed to show a significant change in population or variety on several test units before, during, or after the plateau was noticeable. Apparently this was a situation involving necessary adaptation of organisms or enzyme systems to metabolize the specialized feed. The plateau was never detectable on subsequent feeding of an acclimated system.

Supplementary Nutrients

Certain nitriles indicated a need for materials supplementary to those furnished in Ohio River water. Oxydipropionitrile failed to start oxidation until regular additions of sewage were provided. Lacto- and acrylonitrile systems were appreciably stabilized by sewage addition but usually could get along without it. Oxydipropionitrile oxidations showed a reduction in activity by the second week after sewage was withheld, even in acclimated systems. No explanation was obtained of the precise function of sewage in nitrile oxidations. It does not appear likely that new organisms were involved, in view of the acclimation necessary. Trace nutrients, enzymes, or vitamins in the sewage appear more likely as causes for the beneficial effect on nitrile oxidation. In a surface water, trace materials would be more generally available; the test oxidations were enclosed for varying periods of time which may have resulted in exhaustion of certain nutrients.

Data on the six nitriles investigated make it appear that the cyano-group on a saturated hydrocarbon radical is readily metabolized. Enzymatic hydrolysis leads to the formation of organic acids, ammonia, or associated materials. Other functional groups in the nitrile radically alter the behavior. An electronegative group close to the CN, as in lactonitrile, promotes dissociation of HCN, leading to toxicity. The C-O-C group, as in oxydipropionitrile, stabilized the compound to biochemical action without showing toxic effects. A single unsaturated group as in acrylonitrile increased the resistance to biochemical action but conjugated double bonds, as found in benzonitrile, did not. This suggests that estimates of biochemical stability of different nitriles should depend mainly on the associated functional groups and their relative position in the nitrile.

Summary and Conclusions

Nitrile oxidations show an enzymatic hydrolysis leading to the formation of organic acids and ammonia or associated materials. Both carbonaceous and nitrogeneous oxidation demonstrated a high degree of acclimation. The time required for their adaptation varied with the nitrile under test. Oxydipropionitrile was the most resistant chemical studied, but was rapidly consumed by the organisms after their acclimation.

An acclimated biota was able to metabolize a given nitrile in spite of wide variations in concentration and feeding interval.

Acclimated organisms vary in their response to a different nitrile feed. The more readily metabolized nitriles produced a biota that was not very effective in stabilization of the more resistant nitriles. Organisms capable of assimilating lacto-, and oxydipropionitrile readily used other tested nitriles as a food.

Temperature affects nitrile oxidations in the same manner as it affects other biochemical stabilizations. Acrylo- and oxydipropionitrile required a long adjustment period after the change from summer to winter temperatures.

Organisms adaptable to nitrile oxidation appear to be common in surface

water. Additional nutrients such as those available in sewage were necessary to maintain active growth in laboratory test systems containing certain nitriles. This is probably not a limiting factor for self-purification in most natural water, because of the abundant supply of nutrients from runoff.

After a sufficient adaptation period following nitrile contamination of a surface water, it is unlikely that problems peculiar to the nitriles will be encountered. Aceto-, adipo-, and benzonitrile introduce oxygen demand and nitrate problems. Other nitriles studied introduce certain additional problems. Lactonitrile dissociation leads to the toxic effects of HCN. Acrylo- and oxydipropionitrile require a long time for initial adaptation of organisms and for the adjustment from summer to winter temperatures.

Acknowledgment

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FLOW MEASUREMENT BY RADIOTRACER

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Accurate measurement of rates of liquid flow is admittedly difficult (1). The choice of methods for measuring industrial waste streams is usually limited by the small head available. To review the theoretical bases and practical limitations of the methods most commonly used is to convince the engineer or plant operator of his need for a simple, accurate method to measure flow rates.

Of the methods most commonly used, one of the simplest is the use of a weir. If carefully designed and used, this device has a reasonable accuracy.

A more accurate device, although a much more expensive one, is the Parshall flume. This is a modified venturi flume built to carefully specified dimensions for a given range of flow rates. If the flume is constructed of such materials as to resist scouring, flow rates can be measured with a high degree of accuracy. The useful flow range of a given flume is limited to a factor of less than 100.

One way to determine flow in sewers measures the water depth by continuously recording the back pressure of a gas bubbler. This depth is then related to flow through formulas involving the slope of the sewer, pipe size, wetted perimeter, and other factors. Empirical factors such as pipe roughness lead to errors in flow rate determinations.

This paper describes a basically new method of measuring flow rates. Errors found in the widely-used methods are eliminated with this procedure. It does not require any physical structure such as a weir or a flume and works on any kind, size, or shape of conduit, open or closed. It does not involve the measurement of liquid levels or pressures. It does not require a pressure drop or loss of hydraulic head, and it does not impede the flow in any way. It measures the flow directly in absolute units by a theoretical formula, without empirical correction factors. It is valid over a wide range; thus far, flow rates differing more than a billionfold have been measured.

Theory

This procedure for measuring flow rates is called the total-count method (2)(3). It uses a radioactive tracer, added to the stream to be measured. The principle is as follows. A finite quantity of radiotracer, A, is mixed in the stream. A Geiger counter is fixed in or near the stream some distance below the starting point. While the tracer is passing, clicks from the counter accumulate on the register. After it has all passed, the total number of counts, N, is recorded.

The value of N is inversely proportional to the flow rate, Q, since a slow-moving stream allows more time for counts to accumulate. In addition, the more tracer used, the more counts are recorded. Thus, N is directly proportional to A. Therefore,

$$N = \frac{A}{Q} F \text{ or } Q = \frac{A F}{N} \quad \ldots\ldots (1)$$

where the proportionality factor F is a constant which is characteristic of the isotope, the counter, and its geometrical relationship to the stream.

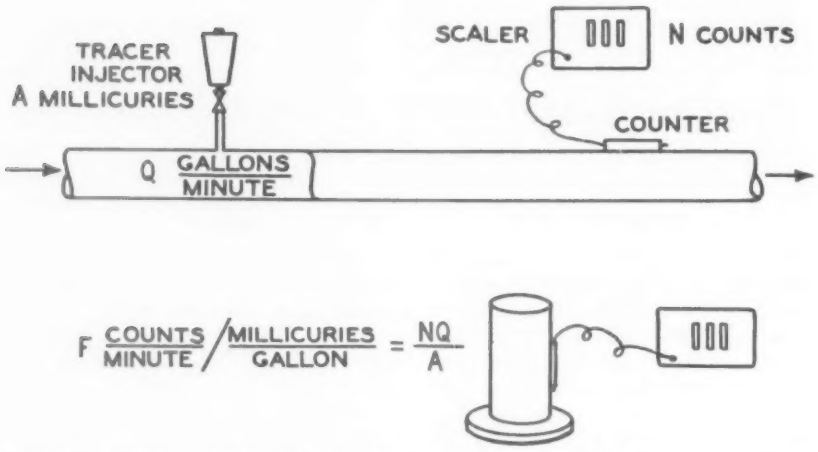

FIGURE 1.—Schematic diagram showing procedure for determination of the proportionality factor, F, in total-count flow rate method.

The dimensions of F are determined by those attached to Q. For example,

$$Q\left[\frac{\text{gal}}{\text{min}}\right] = \frac{A[\mu\text{c}]}{N[\text{counts}]} \times F\left[\frac{\text{counts}}{\mu\text{c}}\right] \times \left[\frac{\text{gal}}{\text{min}}\right] \quad . . (2)$$

The numerical value of F can be determined in the laboratory by the following: A counter is exposed to tracer solution in the same geometrical arrangement as in the field test, to find the counting rate that corresponds to a certain concentration of tracer. This is shown in Figure 1. For example, it was desired to measure the flow of water through an 8-in. pipe with cesium-134 as a tracer. A 2-ft length of the pipe, closed off at one end, was filled with water containing 42.3 μc of cesium-134 per gallon. A 1- by 12-in. Geiger tube, sensitive to gamma rays, was strapped along the pipe. It was connected to a scaler and found to give 222 counts per second. The calibration factor, F, for this pipe, with this isotope and this counter, was then calculated to be 315, with the same units as in Equation 2. If this factor is substituted in Equation 2, the units of microcuries and counts cancel out, and an absolute expression for the flow rate in gallons per minute is obtained.

Divided Streams

The total-count method becomes much more versatile through what is known as the divided-stream principle. It is assumed that the tracered stream in the 8-in. pipe is split, some portion of it being diverted into another line. If x is the fraction of the stream that continues in the 8-in. line, and a counter is placed on the pipe downstream from the wye, the problem is to determine how many counts, N, will be obtained from A microcuries of tracer injected upstream from the wye. The fraction of the tracer that now passes the counter is x, so A is replaced in Equation 1 with xA. But the flow rate at the counter is also reduced in the same proportion, to xQ. Hence, the number of counts is

$$N = \frac{xA\,F}{xQ} = \frac{A\,F}{Q} \quad . . . . . (3)$$

This result shows that the same number of counts is obtained on the fraction, x, of the stream as would be

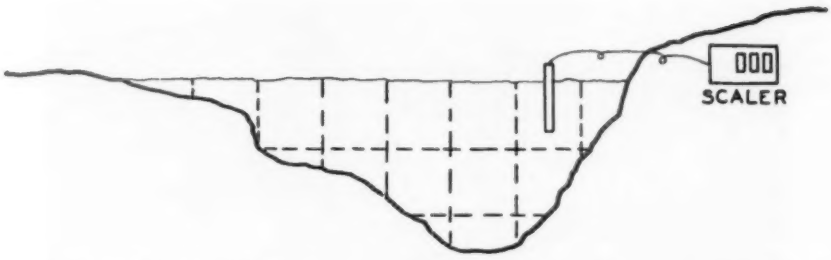

FIGURE 2.—Cross section of an open stream showing imaginary channel partitioning as assumed in total-count flow measurement.

obtained on the whole stream, and it is not even necessary to know the value of x. This fact is important, because it can be applied to gage a large stream by measuring only a small part of it. In a divided stream, the flow rate measured by the total-count method is not that at the point of measurement, but that at the tracer point.

Open Streams

To explain how this principle can be applied to measurement of an open stream, the following description is given and is shown graphically in Figure 2.

The stream is considered as divided by imaginary partitions into a number of channels. The counter is placed in one of these channels so as to respond to tracer atoms that flow past within "gamma-ray range" of the counter. Tracer flowing in more distant channels will not affect the counter for two reasons. First, the exponential absorption of gamma rays in the water limits their penetration to a few feet. Second, the inverse square law rapidly reduces the solid angle covered by the counter.

The channel selected to "count" may carry a current either faster or slower than the average in the stream. In any case, it carries some definite fraction, x, of the total flow. By the divided stream principle, the same total number of counts, N, will be found in this channel as would be found in any other channel in the stream. In fact, the total count is the same as would be obtained if a dam were built across the stream and all the water were forced to flow through this particular channel.

Choice of Isotope

A suitable radiotracer for measuring water flow must be chemically stable in water solution and must emit gamma rays. A radioelement with these properties and also having a long life that permits its stockpiling is cesium-134. It is chemically similar to sodium; almost all of its compounds are readily soluble in water. Its most prominent gamma rays have energies close to 0.7 Mev and are half absorbed by 3.3 in. of water. Its half-life is 2.3 yr, and its cost is $1.00 per millicurie. For small-scale tests, such as described in this paper, it is quite suitable. For larger streams, reasons of economy and safety make it preferable to use short-lived gold-198.

Selection and Calibration of Counter

To obtain high sensitivity, four 1-by 12-in. metal Geiger tubes were connected in parallel and bundled into the bottom of a closed lucite pipe. A cable, 10 to 25 ft long, served to suspend the counter bundle and to connect it to a high voltage source and scaler.

To calibrate the counter for a flow measurement, a part of the channel large enough to give a "saturation"

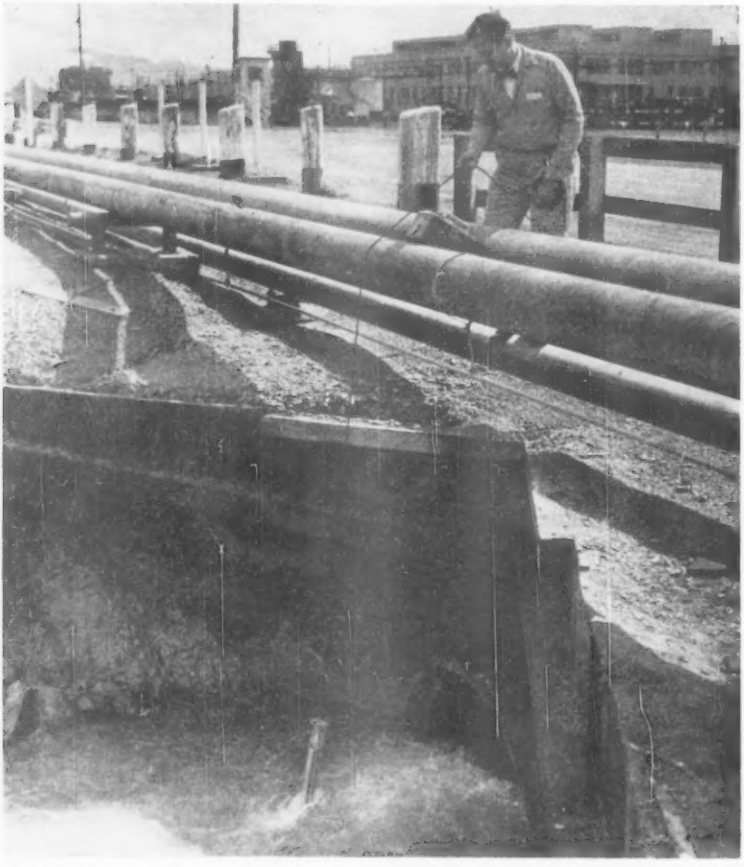

FIGURE 3.—Geiger tube bundle being suspended into refinery waste flow to obtain total-count.

count must be used. This means that the counter must be immersed in a body of tracered water large enough so that making it larger does not supply any more counts. In practice this is accomplished by submerging the counter tubes at least six inches under the surface of the water in a tank 4 or 5 ft in diameter.

The calibration of the tube bundle was made in a tank containing 246 μc of cesium in 574 gal of water. In the solution the counter registered 131.4 counts per second. Thus, from Eq. 1, the factor F is 306 cps/μc/gal. This is more conventionally expressed in units for millions of gallons of water per day. The factor then becomes:

$$F_{mgd} = 306 \times \frac{86,400}{10^6} =$$

$$26.5 \frac{\text{counts}}{\text{microcurie}} \cdot \frac{10^6 \text{ gallon}}{\text{day}}$$

Field Use

The first application of the total-count method to an open stream was on an oil-water separator effluent stream in an oil refinery in California. An enclosed concrete conduit about 9

ft wide carried the effluent 150 ft into an open ditch. The counter was suspended in the stream where it was discharged from the conduit. Figure 3 shows this arrangement. Three tests, placing the counter in three different positions, were made as follows:

1. In midstream, in a strong turbulent current.
2. About two feet from one side of the channel, where the counter swung around in an ellipse alternately in a strong current and in relatively quiet water near the edge.
3. About two feet from the other side of the channel in a region of very strong turbulence where the backwater from a tributary stream merged with the main stream.

In each case the tracer was poured from a pint bottle into the stream through a manhole upstream in the conduit. The results of this test are shown in Table I.

TABLE I.—Results of Flow Rate Tests in An Open Channel Made With Total-Count Method

Position	Tracer (mc)	Counts	Flow Rate (mgd)
1	7.33	7,000	27.7 ± 0.3
2	1.81	1,670	28.7 ± 1.0
3	1.39	910	$40.5 + 2.0$

The check between the first two tests is well within the statistical accuracy of the measurement. This led to two conclusions.

1. The tracer was thoroughly mixed in the stream.
2. The theoretical prediction that the same total number of counts will be found in any channel was verified.

Comparison of the three tests on this stream shows the importance of thorough mixing of the radiotracer in the stream before it reaches the counter. Agreement in the total-count values in different parts of the stream is a criterion of good mixing. The check between positions 1 and 2 testifies to complete mixing above the fork. But the third count, made where the tracered water was diluted with untracered water from the side stream, was too low. Such an effect is to be expected at a confluence and for some distance downstream. Further downstream, after this tributary would be thoroughly mixed with the main stream, a uniformly lower count would be found, corresponding correctly to the higher flow rate of the combined streams.

This first test was made on a stream not equipped with flow measuring devices. Later, an opportunity came to measure a stream that flowed over a broad horizontal weir. With a cesium-134 tracer charge, a flow of 22 3 mgd was found, compared with a weir flow reading of 19.3 mgd.

Sample-Bucket Technique

When the counter bundle is used in a channel of small dimensions, an error is introduced through use of a calibration factor determined for an infinite volume. The correct factor for a narrow channel would be less than that for an infinite volume. For example, in a channel more than four feet wide, the error is less than 1 per cent, but in a 2-ft channel, it may be as much as 10 per cent. To overcome this limitation, another technique was adopted, using the split stream principle described above. In gaging the flow in narrow channels, a small side stream was drawn off through a bucket containing the counter. The counter was calibrated in this same bucket, which eliminated the hydraulics problems characteristic of a narrow open stream.

When the waste is in a closed conduit under pressure, a small bleed stream may be carried through a rubber hose from a sample point on the conduit to a connection in the bottom of the bucket. In many waste streams,

FIGURE 4.—Apparatus used for obtaining small portion of closed conduit waste flow. Pump is shown delivering waste to sample bucket from which tracer count is obtained by the instrument in the background.

because of lack of pressure, this may not be possible; and a pump must be provided to supply a flow through the sample bucket. This arrangement is shown in Figure 4. In calculating the flow rate, the total count obtained in the bucket, the calibration factor determined for the bucket, and the total amount of tracer put in the stream, are substituted in Equation 3 to determine the flow rate in the main stream. It is re-emphasized that the flow rate of the side stream need not be known. However, this flow rate, as well as the flow in the stream, must remain constant during a test to obtain accurate results.

A counting bucket for use in this method was made of a 6-in. tube long enough to submerge the counters in the bundle. The bundle was mounted along the axis of the bucket. The factor for cesium-134 in this bucket was $F_{mgd} = 4.92$ counts/μc. This apparatus has been found especially useful in measuring the flow in sewers, where the dimensions of the flowing stream are rarely large enough to surround the counter with the required mass of water.

In the first demonstration of the total-count method a hose with the end covered with a screen to prevent plugging was dropped through a manhole into a storm sewer. Water was pumped via the hose through the counting bucket at about 40 gpm and returned to the sewer downstream. After a background rate had been established, a bottle of radiocesium

solution was poured into another manhole a block up the street. The results of two successive tests are tabulated below.

Test No.	Tracer (mc)	Counts	Flow Rate (mgd)
1	5.11	4,466	5.64 ± 0.12
2	5.14	4,624	5.47 ± 0.10

The two tests agreed within 3 per cent, the statistical accuracy of the counting. A flow device in use at the measurement point, consisting of a recording pressure gage on a bubbler, showed a value, according to the calibration curve, of 7 or 8 mgd. However, after the tracer test, a more careful look at the friction factor used in the calculations, considering the area of the pipe actually wetted at that level, brought the gage value into close agreement with the total-count value.

Discussion of Method

The total-count method has several advantages over older ways of measuring flow rates. It is simple and versatile. It is inexpensive. With equipment costing less than $1,000, one man can make any of the tests described in this paper in about an hour. The tracer cost is only a few dollars. The method routinely measures flows to 95 per cent accuracy, and with care 98 per cent accuracy is possible. It is a way to check all other kinds of flow meters. However, it is inherent in the method that it does not give a continuous reading of flow rate. Each measurement requires the introduction of a finite amount of tracer, and gives the rate only at the moment. Furthermore, the requirement of mixing limits the method to use in streams where turbulence exists or can be provided. Turbulence is not necessary at the point of measurement, only at the tracer point.

The most serious disadvantage of the total-count method is the fact that it involves radioactive materials. The tracer must be obtained under license from the Atomic Energy Commission, and it must be handled by a person qualified to do it safely. Actually, this is not such a severe handicap as it might seem, because it is not necessary to hire a nuclear chemist for this work. A week of training will enable a person with a technical background to handle these quantities of radioactivity safely; and, under his direction, technicians can be trained in the routine techniques. The most complex operation is to pipette the radioactive solution from one bottle to another without spilling it. The bottle containing the supply—perhaps 10 to 50 mc—must be stored in a lead shield. The larger bottle, containing 1 to 5 mc in dilute solution, need not be shielded. It is safe, for example, to hold it in the hand while emptying it into the stream.

The physiological properties of cesium contribute to the safety of this particular isotope. It is similar to sodium; if taken into the body, it is not stored but is readily excreted. For this reason, the radiological tolerance to this isotope is comparatively high. The accepted figure for the maximum permissible concentration in water used routinely for drinking is 1.5×10^{-4} μc per ml. This amount would give 170 cps in the counter bundle, which is actually a faster rate than should be used for accurate work. In practice, the highest concentration of cesium-134 at the point of measurement is less than that permissible for continuous use, and this concentration persists for only a few minutes.

It is predicted that the gaging of flow in waste streams will be an important use of the total-count method. But its usefulness is by no means limited to this. It can be used in industrial plants to measure flow in pipes where meters have defaulted or

were never installed. With the use of an oil-soluble radioisotope, flow of petroleum stocks can be measured into and out of refining plants. With radiokrypton, gas streams can be measured, whether the exhaust from an automobile or the large overhead stream from a petroleum cracking plant. With radiogold, natural streams and rivers have been measured, up to 1,000 mgd. Many other uses are predicted for this method which covers the whole field of flow rate measurement.

References

1. American Petroleum Institute, "Manual on Disposal of Refinery Wastes." **1**, 59 (1953).
2. Hull, D. E., "Total-Count Technique in the Refinery." *Ind. Eng. Chem.*, **50**, 199 (1958).
3. California Research Corporation, "Fluid Flow Measurement." U. S. Patents 2,826,699 and 2,826,700.

MEETINGS OF INTEREST

1959

Jan. 26–30 **Water and Sewage Plant Operators' School,** University of Colorado Denver Extension Center. Write to: Water and Sewage Plant Operators' School, Room 305, 1165 Broadway, Boulder, Colo.

Feb. 1–6 **American Institute of Electrical Engineers,** Statler and Sheraton-McAlpin Hotels, New York, N. Y. Raymond C. Mayer and Associates, 36 West 46th St., New York 36, N. Y.

Feb. 2–6 **American Society for Testing Materials** (Committee Week), Penn-Sheraton Hotel, Pittsburgh, Pa. American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

Feb. 12–13 **Florida Water Resources Conference,** University of Florida, Gainesville, Fla. Write to: Department of Water Resources, The Capitol, Tallahassee, Fla., or the Public Service Training Center, 28 Dining Hall, Florida State University, Tallahassee, Fla.

Feb. 15–19 **American Institute of Mining, Metallurgical, and Petroleum Engineers,** San Francisco, Calif.

Mar. 16–20 **National Association of Corrosion Engineers,** Sherman Hotel, Chicago, Ill.

Mar. 17–18 **Air and Water Pollution Abatement Conference,** Netherlands Hilton Hotel, Cincinnati, Ohio. Manufacturing Chemists Association, Inc., 1625 Eye St., N. W., Washington, D. C.

Apr. 2–3 **Eighth Southern Municipal and Industrial Waste Conference,** University of North Carolina, Chapel Hill, N. C. Dr. Daniel A. Okun, Dept. of Sanitary Engineering, School of Public Health, University of North Carolina, Chapel Hill, N. C.

Apr. 5–10 **American Chemical Society,** 135th National Meeting, Boston, Mass. R. M. Warren, American Chemical Society, 1155 16th St., N. W. Washington 6, D. C.

Apr. 5–10 **Fifth Nuclear Engineering and Science Conference,** Public Auditorium, Cleveland, Ohio. T. A. Marshall, Jr. (Congress Manager) or L. K. Wheelock (Assistant Manager), c/o Engineers Joint Council, 29 West 39th St., New York 18, N. Y.

WASTES FROM THE POTATO CHIP INDUSTRY

By Ralph Porges and W. W. Towne

Robert A. Taft Sanitary Engineering Center, Public Health Service, Department of Health, Education, and Welfare, Cincinnati, Ohio

During recent years the potato chip industry has grown into a food-processing prodigy. In 1957, 45 million bushels of potatoes—nearly 12 per cent of the entire crop—were processed into chips (1). This fast growth has hastened the change from intermittent, batch processes to continuous, virtually automatic, operations. Associated with this growth are new waste disposal problems and larger demands on water supplies.

This study was undertaken because of the interest shown by industry, regulatory agencies, and others concerned with water use and waste disposal; and because of the paucity of reported data. An earlier report of waste loadings from potato chip processing (2) was limited to a study of one small plant.

The goal of the present study was to facilitate industry's understanding of plant processes as they relate to water use and waste discharges, and to permit evaluation of the wastes produced from a knowledge of the process, the amounts of raw materials utilized, and the finished product.

Processes and Waste Sources

Historical

The potato chip originated at "Moon's Place," Lake Saratoga, N. Y., around 1853 (3). The paper-thin slices of potatoes, chilled in ice water, dried, and fried in boiling fat, became known as Saratoga chips. It was not until 1925 that a company was organized solely for making the chips. With increasing sales, mechanical peelers and slicers were developed and processing proceeded from batch to semicontinuous and continuous operation.

By 1936, three million bushels of potatoes were chipped; in 1946, 15 million bushels; and in 1956, 45 million bushels (4). Statistics for 1957 indicate that nearly 12 per cent of a total potato crop of 394 million bushels was used for chips (1).

Raw Materials

The potato is the most important item in the science and art of chipping. It must produce a light-colored chip with eye appeal and have a solids content that assures a profitable enterprise. High sugar content and nitrogenous portions of the potato cause the undesirable dark chip, a condition which is controlled by selection of potato variety, growing conditions, and type of storage.

For economical processing, the potato should have a high density which can be determined by analysis or estimated from the specific gravity. Since specific gravity can be more easily assayed and is indicative of production volume, the potatoes are usually received at the plant with their specific gravity recorded. The Department of Agriculture states (5) that the correlation between specific gravity and dry matter has usually been found to be very high, with correlation coefficients varying from 0.85 to 0.95. It indicates that results computed by the following formula developed by Von Scheele, Svensson, and Rasmussen seem to approach analytical results:

Percentage dry matter = 211.04
× specific gravity − 207.709.. (1)

Similarly, the starch content may be estimated from the specific gravity by the formula given by Von Scheele *et al.* (5):

Percentage starch = 199.07
× specific gravity − 201.172.. (2)

The estimated solids and starch content of potatoes at a given specific gravity is found in Table I.

TABLE I.—Calculated Solids and Starch Content of Potatoes at Various Specific Gravities

Specific Gravity	Solids (%)	Starch (%)	Starch in Solids (%)
1.06	15.99	10.16	63.3
1.07	18.10	12.15	67.2
1.08	20.21	14.15	70.0
1.09	22.32	16.14	72.3
1.10	24.44	18.14	74.2

A standard potato may be assumed to contain about 20 per cent solid matter and 80 per cent water; the starch content ranges from 65 to 75 per cent of the dry weight (6). Other information indicates that the solid matter may average as high as 25 per cent (2). The variety of potato influences these values although the 20-per cent figure might prove a more realistic average. The varieties best for chipping include Russet Rural, Russet Burbank, Smooth Rural, Irish Cobbler, New Kennebec, Canus, Sebago, Katahdin, and Cherokee (3)(4).

After the potato the next important raw material is the cooking oil. This oil is generally a high-grade vegetable product.

Plant Operation

The original recipe as carried in the early cook books is still the basis for successful chips. However, the original batch process (2) is largely superseded by semicontinuous or continuous operation. Production operations in all the plants visited during this survey were essentially of the continuous type and, except for minor variations, may be represented by the flow diagram in Figure 1.

The potatoes, in 100-lb sacks, are taken from storage and conveyed to a peeler equipped with high-speed abrasive disks. The potatoes are then washed, trimmed, and sliced, yielding 15 to 20 slices per inch. The slices are moved to a wash cage that rotates in a tank or trough of water. Unwanted starch is removed by a double rinse to prevent matting or sticking of the chips. After partial drying, the slices are dropped into the deep-fat cookers. The chips are then salted and packaged.

There are, of course, variations in the process. Some plants discharge the final rinse to the wash tank which

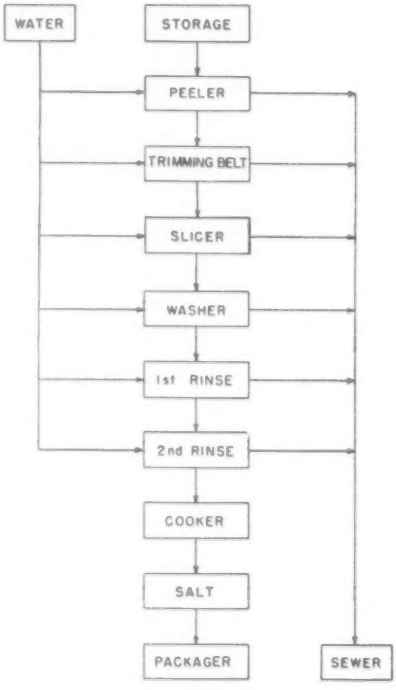

FIGURE 1.—Flow diagram of potato chip processing showing waste sources.

overflows to waste. One plant strains the peeler waste through burlap and the residual solids plus those settled in the wash tank are collected by a farmer for hog feeding. Another plant grinds all solids to facilitate water carriage of the waste. Most plants favor wasting to the sewer as a good housekeeping procedure.

The primary sources of wastes are shown in Figure 1. Wastes derive from the peeler, trimming belt, slicer, wash, and rinse operations. Clean-up wastes, small amounts of waste oil, and sanitary sewage substantially comprise the remainder of the total waste load.

Method of Study

A series of studies of wastes from potato chip plants was made by the Sewage Disposal Section of the City of Cincinnati. These studies consisted of 24-hr per day sampling for four or five consecutive days. The weighted, average BOD, suspended solids, and discharge values were used in this study. Full recognition is made of the cooperation of personnel of the Sewage Disposal Section of the City of Cincinnati who permitted the use of this information.

The individual potato chip plants were solicited, either through the cooperation of the National Potato Chip Institute or by direct communication, for assistance in providing data on materials and production during the sampling period. In all instances, the industry responded promptly and willingly.

The data solicited included pounds of potatoes processed and their solids content and specific gravity, volume of chips produced, oil content of the chips, number of employees, and details of the process. Earlier information (2) was used to supplement the new data collected.

All results were compiled on the basis of a production unit of 1,000 lb of potatoes processed. In addition, a laboratory determination was made of the BOD of potato solids permitting correlation of the observed BOD in the sewer with that estimated from the pounds of dry potato solids discharged to the sewer.

Results

Unit values relating to plant operation and chip processing are shown in Table II. An average of 250 lb of chips is produced for each 1,000 lb of potatoes handled. Actual production ranges from 240 to 260 lb. Forty per cent of the final weight of an average chip consists of absorbed oil and the moisture content runs from 2 to 2.5 per cent. Water used per 1,000 pounds of potatoes varies from 1,450 to 2,480 gal, averaging 1,990 gal. Pounds of BOD per 1,000 pounds of potatoes range from 14.5 to 30.8. Pounds of suspended solids per 1,000 pounds of potatoes vary from 20.4 to 36.4.

TABLE II.—Plant Operation and Wastes Discharged per 1,000 Pounds of Potatoes Processed

Plant	Month	No. of Employees	Potato Chips* (lb)	Waste Flow (gal)	BOD		Suspended Solids	
					(ppm)	(lb)	(ppm)	(lb)
A	July	0.9	240	2,480	730	15.0	820	24.3
B	Dec.	1.3	260	2,020	1,560	26.2	2,140	35.9
C	Oct.	1.0	240	2,000	1,850	30.8	2,190	36.4
D	Dec.	2.3	255	1,450	1,200	14.5†	1,700	20.4†
Avg		1.4	250	1,990				

* Average weight of oil on finished chip is 40 per cent.
† Much solid material was removed manually and did not reach the sewer.

TABLE III.—Solids Balance and BOD Relationship per 1,000 Pounds Potatoes

Plant	Dry[a] Wt. of 1,000 lb Potatoes (lb)	Chips[b] Produced		Oil[c] in Chips (lb)	Dry Solids[d] Produced (lb)	Solids[e] Lost (lb)	BOD[f] of Solids Lost (lb)	BOD in Sewer (lb)
		Actual Wt. (lb)	Dry Wt. (lb)					
A	177	240	234	96	138	39	17.7	15.0
B	210	260	254	104	150	60	27.2	26.2
C	200	240	234	96	138	62	28.1	30.8
D	210	255	249	102	147	63	28.5	14.5[g]
Avg	200	249	243	100	143	56	25.4	25.0

[a] Dry-solids variation probably seasonal.
[b] Average moisture content about 2.5 per cent.
[c] Chip contains 40 per cent oil.
[d] Subtract weight of oil from dry weight of chips produced.
[e] Subtract weight of dry solids produced from dry weight of 1,000 lb of potatoes.
[f] BOD per pound of solids = 0.453.
[g] Omitted from average as much solid material removed manually. Replaced by adjusted value of 28.1.

Variation in unit values may be caused by seasonal influences on the quantity of water used, the maturity and solids content of the potato, the quality and exterior roughness of the potato, and the method of handling peelings and other solid wastes. The month of sampling is shown in Table II.

Discussion

Solids Content—BOD Relationship

The growth of the chipping industry may be expected to continue, with a concomitant expansion of the water problem. Considering that 45 mil bu or 2,700 mil lb of potatoes are chipped per year, the daily amount is roughly 10 mil lb. Approximately 20 mil gal of water are required each day to process these potatoes.

The potato chip plants studied are probably representative of the industry. They vary in size, processing from about 5,000 to 30,000 lb of potatoes per day.

Waste from a potato chip plant varies with the season as it influences the types of potatoes used and, consequently, the method of processing. It is reasonable to believe that as the solids content of the potato increases, the oxygen-demanding properties of the gross waste material will also increase. Also, if solid materials such as peelings and small pieces of potatoes are removed for disposal by means other than water carriage, the waste load will be reduced. Plant A (Table II) at the time of the study (July) was handling a potato with low solids and it will be noted that the quantity of BOD produced was low. Plant D was removing solid material from the waste flow, with a corresponding reduction in the strength of the waste discharged. Plants B and C were studied in the fall (October and December) and the waste values were in close agreement and much higher than values for Plants A and D.

It was decided to evaluate the process on a dry-solids basis and compare a calculated waste load with the actual waste load. For each plant, the following information, if available, was collected: (a) per cent dry solids in potatoes processed or specific gravity, from which the solids content was determined, (b) pounds of chips produced, (c) amount of oil in the chip, and (d) pounds of potatoes processed. The results of this evaluation are shown in Table III.

The BOD of a raw potato was determined in the laboratory. Two individual runs were made with the following results:

Run	Solids (%)	BOD (ppm)	lb BOD/ lb Solids
A	18.57	84,000	0.452
B	18.70	85,000	0.455
Avg	18.64	84,500	0.453

Notice that for each pound of dry solids a BOD of 0.453 lb will be exerted. Thus, by multiplying the dry potato solids lost by 0.453 the quantity of BOD discharged can be computed. The last column of Table III gives the BOD obtained from an analysis of the waste. Comparison of the results of determining the waste load by the two independent methods (last two columns of Table III) is extremely good. Deleting results for Plant D because of manual removal of much of the solids and adjusting for the remaining data, the calculated average BOD based on solids lost is 25.4 lb, while that obtained from an analysis of the waste in the sewer is 25.0 lb. The BOD population equivalent for each 1,000 lb of potatoes processed with the above characteristics would be about 150.

Population Equivalent

A previous study of potato-chip processing wastes (2) indicated a BOD population equivalent of 65 per 1,000 pounds of potatoes. This estimate is low when compared with the present value of 150 per 1,000 pounds. However, that study was made on a batch process and some solid materials such as sprouts and possibly peelings were hauled to a dump. The report (2) stated that the data were limited to a single plant and might not be truly representative of waste loadings at other plants.

Several reports of wastes from potato dehydration processes appear to be of interest since these wastes may compare grossly to the wastes from chipping plants. Gray and Ludwig (7) show dehydration wastes to contain 40 lb of BOD per ton of potatoes processed, amounting to 120 population equivalents per 1,000 pounds. Jones (8) reports a population equivalent of 12,000 for 40 tons of potatoes, or 150 per 1,000 pounds, which compares to results from the present study. DeMartini, Moore, and Terhoven (9) reported on two separate dehydrating plants. One plant discharged 3.28 pounds of BOD per 100 pounds of potatoes, or a population equivalent of 198 per 1,000 pounds. The other plant discharged 4.57 pounds per 100 pounds or a population equivalent of 274 per 1,000 pounds of potatoes.

The variation in these data probably results from the variety and maturity of potatoes used and the processing methods employed. A smooth potato with thin skin produces less waste than a rough potato with thick skin. Evaluation of the wastes from these processes on the basis of dry solids lost to the sewer would bring these studies to a common basis and might indicate a closer agreement.

Waste Volume

The volume of water used is a matter of importance both from the water-cost and disposal viewpoints. Generally, a reduction in volume decreases sewage disposal costs, although surcharges based on pounds of BOD or suspended solids probably will not change. Some attempts have been made to reuse water, particularly that clearer portion of the rinse waters. Filtering of the water prior to reuse has not proved practicable as the starch particles rapidly clog any filter medium. Application of the countercurrent principle appears promising especially since the initial machine, the peeler, does not require high quality water. It would seem that considerable water could be saved by pumping the final rinse waters to the wash tank and using the wash-tank

overflow to feed the peeler and then discharging it to the sewer. No filtering or water conditioning would seem to be necessary.

Housekeeping

The method of housekeeping also influences the waste load. Where peelings and solid wastes are removed manually for dry disposal, the waste load is reduced appreciably. Plant D practiced this method and the BOD of the waste was reduced to nearly 50 per cent of that estimated from the solids balance. Other plant operators feel that disposal to the sewer facilitates the handling of waste solids.

As previously stated, the BOD estimated from the solids balance approximated that obtained from the liquid waste. Thus, a question arises concerning the accountability of the sanitary sewage and clean-up wastes. The amount of those wastes appears limited and probably does not influence the total load appreciably. The number of employees per 1,000 pounds of potatoes averages only 1.4. In addition, some organic matter probably passes out through the ventilating stack during the cooking process. Cooking takes place at temperatures varying from 375 to 325°F. When the raw chips reach the kettle, clouds of steam are generated. The steam probably contains some oil and volatile organic material from the potato.

Disposal

Probably the best method of waste disposal is discharge to a sewer for treatment with the municipal wastes. This method was employed by the several plants studied. Since chipping wastes are similar to canning wastes, treatment might be similar to that employed by canneries. A chipping plant is reported (10) as planning to use a holding lagoon followed by spray irrigation. Odors from the lagoon will be controlled by aeration. Sodium nitrate applications may be of some value. With suitable soil and proper land management, this method may prove satisfactory and results from this installation should be of considerable interest.

Trickling filters have been employed for treating canning wastes although the seasonal operation of canneries makes it difficult to develop effective treatment units. Year-round operation of potato chip plants should permit more effective operation of trickling filters. Chemical coagulation has been used for partial treatment where untreated wastes may overload small municipal treatment plants. With the increasing importance of satisfactory waste disposal, industrial sites that minimize the waste problem should be selected.

Summary

The potato chip industry in 1957 used 45 million bushels of potatoes or 12 per cent of the total crop. Because of the interest in water usage and waste disposal, a study was made of several potato chipping plants to obtain representative values of water use and waste strength. The study involved analysis of data from a survey of chipping plant wastes and correlation of the data with production figures and processing methods.

The potato chipping process consists of peeling, trimming, slicing, washing, rinsing, drying, cooking, and packaging. Wastes originate primarily from the peeling, trimming, washing, and rinsing operations.

Representative data from a study of four plants show that for each 1,000 lb of potatoes handled the volume of waste amounts to 1,990 gal; the BOD amounts to 25 lb; and the suspended solids amount to 33 lb.

Waste products vary with the potato variety and method of processing. If preliminary estimates of plant wastes must be made without a sampling study, it will be advantageous to use as a basis for computation the

dry solids lost in production. Excellent agreement was found between a calculated and an "actual" BOD. The average BOD estimated from solids wasted per 1,000 pounds of potatoes was 25.4 pounds. This compares to the 25.0 pounds actually found in the sewer.

A dry solids balance can be computed using the solids content of the potato and the pounds of chips produced after allowing for the oil and moisture content of the finished chip. Since it was found that each pound of dry potato solids exerts a BOD of 0.453 lb, use of this conversion factor permits computation of the total BOD load from quantity of solids lost. If all wastes reach the sewer, the computed value will reasonably approach the BOD of the discharged liquor. Should some solids be removed for manual disposal, the value must be adjusted accordingly.

A counter-current principle of water use would seem to hold promise for reduction of water consumption and of waste discharge. Although manual removal of solids reduces the waste load, the choice between manual and water-carried disposal is a matter of economics and cleanliness, and is one that management must make.

The residual amount of waste will require disposal. Discharge to the municipal sewerage system, with or without pretreatment, is probably the best method. Other methods that might be considered are lagooning with land application or spray irrigation, and trickling filters. Industrial plant sites that minimize waste disposal problems should be selected.

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FACTORS AFFECTING THE AERATION EFFICIENCY OF SEWAGE AND INDUSTRIAL WASTES *

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Aeration in waste treatment is used principally for the transfer of oxygen in the activated sludge process. This oxygen transfer is usually accomplished by diffusion from air bubbles discharged from submerged orifices. In cases where high transfer rates are required a turbine is employed to increase the turbulent mixing and the mass transfer rate.

The rate of oxygen transfer depends on the nature of the diffusion device, the submergence depth, and the air-flow rate. In addition, the chemical nature of the waste mixture will affect the rate of oxygen diffusion.

Theory

The mass transfer of oxygen from air to water is expressed by the relationship (the symbols used throughout this paper are defined in the Appendix):

$$R = K_L A (C_s - C_L) \quad \ldots\ldots (1)$$

Expressed in concentration units Eq. 1 reads:

$$dC/dt = K_L A/V (C_s - C_L) = K_L a (C_s - C_L) \quad \ldots (2)$$

Since the measurement of interfacial areas is impractical in most cases, the over-all coefficient, $K_L a$, is usually employed to define the aeration process.

In the aeration of activated sludge, Eq. 2 must be further modified to account for the effect of oxygen utilization by the sludge-liquid mixture (1) (2):

$$dc/dt = K_L a (C_s - C_L) - r_r \quad \ldots (3)$$

Under steady-state operation, $dc/dt = 0$ and Eq. 3 becomes

$$K_L a = \frac{r_r}{C_s - C_L} \quad \ldots\ldots (4)$$

It is apparent from the foregoing relationships that the rate of mass transfer will depend on the magnitude of the liquid film coefficient K_L and on the interfacial area-volume relationship, A/V.

Unpublished studies by the author indicate that, for bubble aeration in a column of water, where surface aeration is negligible, K_L is related to the velocity of bubble rise, the liquid submergence depth, and the diffusivity:

$$K_L = \frac{\beta v_b}{h^m S_c^{0.5}} \quad \ldots\ldots (5)$$

In Eq. 5, S_c is the Schmidt Number relating diffusivity and kinematic viscosity.

The interfacial area-volume relationship, A/V, for diffused aeration may be expressed:

$$\frac{6\, G_s h}{d_b v_b V} + \beta_1 \left(\frac{1}{h}\right) \quad \ldots\ldots (6)$$

The first term expresses the area-volume relationship for the bubble surface and the second for the tank surface.

For depths normally employed in aeration practice (10 to 15 ft) the term $1/h$ becomes small with respect to the bubble surface and can usually be neglected. For example, in an aeration tank of 15 ft depth with an air flow of 20 cfm per 1,000 cu ft of tank volume and a bubble diameter of 0.1 in., A/V for the bubbles will be 1.8 and for the

* Presented at the 13th Industrial Waste Conf., Purdue University; Lafayette, Ind.; May 5–7, 1958.

surface, 0.067. The term, $1/h$, represents a smooth surface, but because of the high degree of surface turbulence the interfacial area will be considerably greater. To compensate for this a constant, β_1, is included in Eq. 6 ($\beta_1 \geq 1.0$). Equations 5 and 6 can be combined to define the over-all coefficient, K_La, where the surface effect on the A/V ratio is neglected:

$$K_La = \frac{\beta G_s h^{1-m}}{V d_b S_c^{0.5}} \quad \ldots\ldots\ldots (7)$$

At the high air-flow rates normally employed in aeration practice the bubble diameter can be related to an exponential function of the gas rate:

$$d_b = \beta_2 G_s^n \quad \ldots\ldots\ldots (8)$$

The exponent, n, relates to both variation in bubble size with air-flow rate and turbulence as influenced by tank geometry. Equation 7 can be combined with Eq. 8 for any operating temperature:

$$K_LaV = N\, G_s^{1-n} h^{1-m} \quad \ldots\ldots (9)$$

in which

$$N = \frac{\beta}{\beta_2 S_c^{0.5}}$$

A similar relationship was developed by King (3) to define the performance of diffuser plates in activated sludge spiral-flow aeration tanks:

$$K_La = \frac{\beta_3 h^z G_s^{x'}}{d_b^{x''}} \quad \ldots\ldots (9a)$$

in which the magnitude of the exponents x, x', and x'' depends on the percentage of diffuser plate area on the tank bottom.

Equation 9 can be employed to characterize the performance of any diffused aeration device. For comparative purposes it is convenient to express Eq. 9 as an absorption number, N:

$$N = \frac{K_LaV}{G_s^{1-n} h^{1-m}} \quad \ldots\ldots (10)$$

In Figure 1 oxygen transfer data for a sparger unit in a circular aeration tank

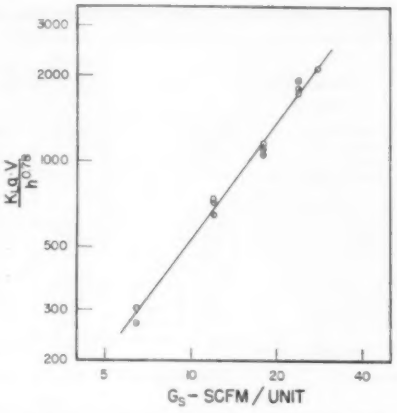

FIGURE 1.—Oxygen transfer characteristics of a sparger aeration unit.

are correlated according to Eq. 10. Values for typical diffusion units in water and various wastes are shown in Table I.

When turbine aeration is employed, the bubble size and hold-up are influenced by both air rate and turbine speed. The bubble diameter has been shown to vary inversely as the three-halves power of the peripheral speed (4). Oxygen absorption in the turbine aerator will be related to the air-flow rate and the power input to the rotating agitator. A general relationship which has been employed is (5):

$$K_La = \beta_4 V_s^{\phi} N^{\phi'} \quad \ldots\ldots (11)$$

Data for two types of turbines aerating domestic sewage and a pulp and paper mill waste are shown in Figure 2.

Aeration Devices

The oxygen transfer capacities of the various types of aeration equipment now in use are primarily related to the size of bubble generated and the velocity gradients established in the tank liquid.

Brief descriptions of the more common aeration devices follow:

1. Small orifice diffusion units. These units are placed permanently in the

TABLE I.—Oxygen Transfer Characteristics of Diffused Aeration Equipment

Diffuser Unit	Waste	Absorption Number, N	Exponent, $1-n$	Depth, h (ft)	Description
Aloxite tubes*	Sulfite	270	0.85	15	Three units in 12 × 5 ft tank; operating temp., 20°C; new clean tubes.
Plastic tubes*	Sulfite	160	1.0	15	
Sparger*	Sulfite	61	1.35	15	
Impingement*	Sulfite	145	1.10	15	Three units in 12 × 5 ft tank; operating temp., 20°C; impingement liquor flow, 18 gpm; air flow range, 8 to 16 scfm per unit.
Disc-type†	Sulfite	92	1.20	13	Column diam., 30 in.; depth, 13 ft.
Sparger	Sewage	213	0.86	15	Aeration tank 30 ft wide, baffled walls; high-rate activated sludge; SS-2000 ppm.
Sparger	Sewage	207	0.86	15	
Sparger	Pulp & paper	57	1.35	15	Two units placed on center line of one-half of a 14-ft diam. tank.
Disc-type	Pulp & paper	168	0.95	15	Aeration bay 116 ft long; surface area 2780 sq ft; activated sludge; SS-2000 ppm; 100 units/bay.
Sparger	Pulp & paper	279	0.81	15	
Impingement	Pulp & paper	195	1.10	15	
Impingement	Pulp & paper	108	1.10	15	Same as above but after six months service; units were partially clogged.
Carborundum plates‡	Water	65	0.80	26	Tanks 137 × 22 × 26 ft deep; diffuser plate area equaled 12% of tank area.
Jet	Pharmaceutical	710	1.00	4	Shutte-Koerting jet #008K; flow, 3–5 gpm at 20 to 65 ft head in 55 gal drum.

* Ref. 7.
† Data of Chicago Pump Co.
‡ Ref. 3.

bottom of an aeration tank (plates) or suspended from flexible joints along the side wall of a tank (carborundum and plastic tubes). When air is diffused through these units a helical or screw motion is imparted to the sludge-liquid mixture.

2. Sparger units. These units contain four short tube orifices. The four tubes are in the form of a cross from which air is emitted at high velocity.

3. Disc-type units. These units emit air from the periphery of the disc. The operating characteristics of this unit appear to be similar to those of the sparger unit.

4. Impingement aerator. This unit employs a liquid stream, air-lifted from the aeration tanks, as a shearing device for air bubbles discharged from a large orifice.

5. Jet aerator. This unit pumps liquid from the aeration tanks through a piping manifold. The device aspirates and disperses atmospheric air or air from a blower.

6. Turbine aerator. This unit utilizes a rotating turbine or agitator to

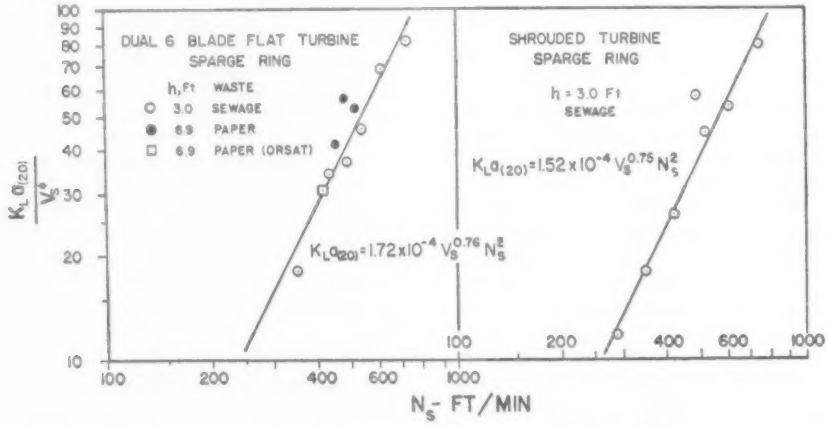

FIGURE 2.—Oxygen transfer characteristics of turbine aeration units.

disperse compressed air by a shearing and pumping action.

Factors Affecting Oxygen Absorption

Effect of Air-Flow Rate

The volume of bubbles produced from small orifice diffusion units is related to the orifice size. For carborundum plates (3) the diameter of air bubbles has been found to vary from 0.20 to 0.43 cm over a permeability range of 40 to 120.*

The mean diameter of bubbles produced at high air-flow rates is an exponential function of the flow rate as shown by Eq. 8. Data from four diffusers employed by Pasveer (6) showed the exponent, n, to vary from 0.10 to 0.44.

In evaluating aeration equipment it is more convenient to consider the exponent, $1-n$, as related to the over-all coefficient, K_La (Eq. 9). The exponent will also reflect the effect of tank turbulence and geometry as previously noted.

For small orifice diffusion units (carborundum plates and tubes, seran tubes, etc.) the exponent is less than 1.0, indicating an increasing bubble size with increasing air flow. For carborundum plates, King (3) has shown an increase in bubble size of 10 per cent over an air-flow range of 1 to 4 cfm. Over a wide range of bubble fineness and dispersion, Gaden and Hixon (2) showed the exponent, $1-n$, to vary from 0.33 to 0.82. For these devices, when $1-n$ is less than 1.0, the absorption efficiency decreases with increasing air-flow rates. Data for several commercial orifice diffusion units are tabulated in Table I. The transfer characteristics of several aeration devices are shown in Figure 3.

In the case of high air-flow rates using the sparger and disc-type units, tank turbulence tends to redivide larger bubbles into smaller bubbles increasing both the surface renewal rate and the

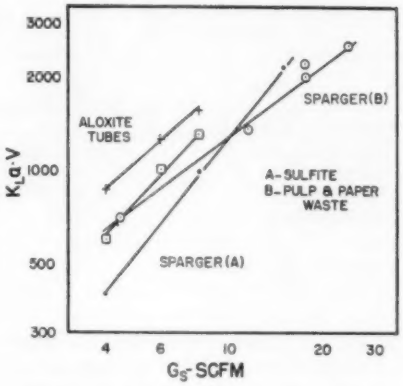

FIGURE 3.—Oxygen transfer characteristics of several aeration devices.

A/V ratio. When this occurs, the exponent, $1-n$, may be greater than 1.0, resulting in increased transfer efficiency. This phenomenon, however, is related also to tank geometry and the location of the diffuser unit. It will be observed from Table I that sparger units centrally located in the sulfite test tank showed exponents greater than 1.0. For similar units in the sewage and pulp and paper waste tanks the exponent was less than 1.0. Similar effects were reported for the disc-type unit in studies conducted by the Chicago Pump Company. This emphasizes the importance of relating absorption efficiency to actual tank conditions.

The bubble size released from the impingement aerator depends on the quantity of impingement liquor delivered by the circulating air-lift pump. Absorption has been shown to increase linearly with impingement-liquor flow (7).

The exponent, $1-n$, for a jet aerator has been found to be 1.0, indicating no change in bubble characteristics with air flow. The absorption efficiency has been found to remain constant over the range for which data are available.

Effect of Depth

The oxygen transfer process in diffused aeration occurs in three phases:

* Permeability is defined as the volume of air (cfm) passing through 1 sq ft of diffuser surface at 70°F, 25 per cent relative humidity, and a pressure loss of 2 in. of water.

TABLE II.—Some Values of Depth Exponent, $1-m$

System	Exponent, $1-m$
Diffuser in still water column	0.67
Plate diffuser*	0.71–0.77
Sparger	0.78
Aloxite tube†	0.45
Impingement†	0.65

* Data of King (3).
† Data of Dreier (7).

(a) during bubble formation; (b) during bubble rise; and (c) through interface renewal at the tank surface (7). Surface aeration is caused by the shedding of oxygen-saturated films when the bubble bursts and from reaeration induced by velocity gradients. Since the relative values of the film coefficient during bubble formation and surface aeration are greater than the coefficient during bubble rise, the over-all coefficient will decrease with increasing depth. Over the range of depths employed, the over-all coefficient, K_La, in industrial waste aeration systems can be approximated by an exponential function of depth. The depth exponent, $1-m$, has been determined experimentally for several diffused aeration systems. These values are summarized in Table II. There is some experimental evidence that the depth exponent, $1-m$, for turbine aerators approaches 1.0, indicating no change in absorption with tank depth. This is not unreasonable when one considers that the fluid regime of a turbine aeration system approaches a homogeneous condition at all depths.

Effect of Circulating Velocity

The rate of interfacial renewal in an aeration tank is proportional to the velocity of the bubble relative to the tank liquid. High circulating velocities will produce large values of the liquid-film coefficient, K_L. In addition, interfacial renewal rates at the tank surface will be related to velocity gradients at the surface.

The horizontal velocities in aeration tanks for several commercial diffusion

TABLE III.—Velocity Variations with Various Aeration Devices

Depth (ft)	Horizontal Velocity[a] (fpm)			Horizontal Velocity[b] (fpm)			Horizontal Velocity[c] (fpm)		
	A[d]	B[e]	C[d]	A[d]	B[e]	C[d]	A[f]	B[e]	C[f]
½	2.35	2.97	—	—	2.23	—	3.34	2.77	2.23
1	—	2.47	—	—	1.40	1.36	—	2.14	1.75
1½	1.21	—	—	—	—	1.10	1.98	—	—
2	—	—	—	—	0.97	1.05	—	1.51	1.33
3	1.16	0.91	—	0.74	0.88	0.74	1.48	1.21	1.13
4	—	0.88	—	0.75	0.63	1.10	—	—	—
5	—	0.77	—	0.70	0.50	0.79	—	—	—
6	1.03	0.73	0.74	0.47	0.52	0.67	—	—	—
8	—	1.13	—	0.49	0.70	0.85	—	—	—
10	1.40	—	1.16	0.51	0.71	1.13	—	—	—
12	1.60	1.72	1.13	—	1.10	1.05	—	—	—
14	—	—	—	—	1.44	1.23	—	—	—

[a] Pulp and paper waste; aeration tank depth, 15 ft; width, 24.5 ft; spargers delivering 30 scfm per 1,000 cu ft of tank volume.
[b] Pulp and paper waste; aeration tank depth, 15 ft; width, 24.5 ft; impingement diffuser delivering 28 scfm per 1,000 cu ft of tank volume.
[c] Sewage; aeration tank depth, 15 ft; width, 34.75 ft; double row of diffuser plates delivering 18 scfm per 1,000 cu ft of tank volume; Ref. 4.
[d] At 8 ft from tank center line.
[e] At center line.
[f] At 9 ft from tank center line.

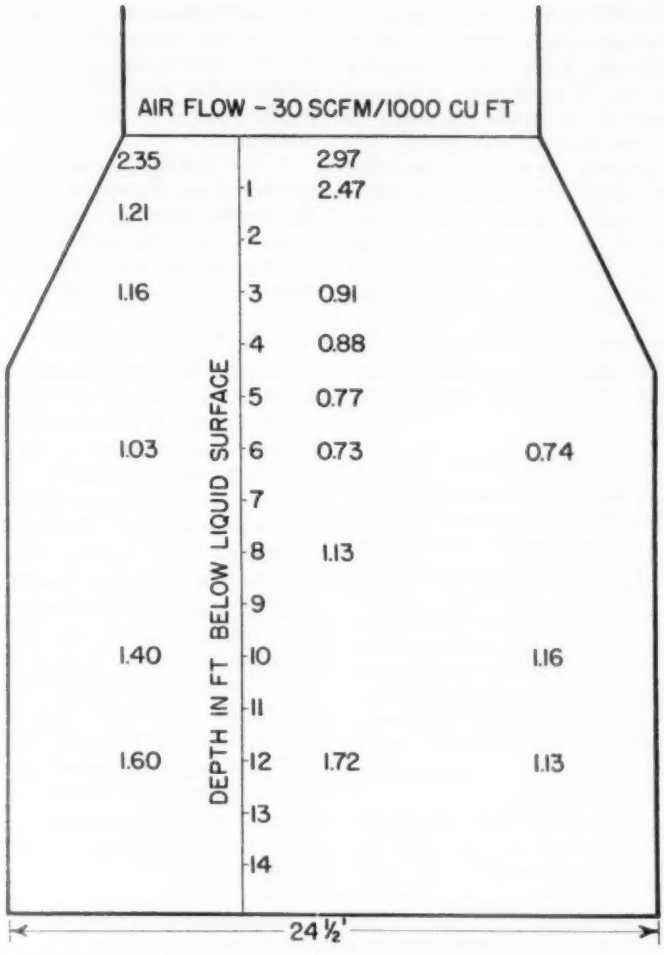

FIGURE 4.—Circulating velocities (fps) in an activated sludge aeration tank.

devices are summarized in Table III. The surface velocity measured by King (3) in a 34-ft-wide aeration tank was found to vary from 4.3 fps above the diffuser plates to 2.1 fps near the side wall opposite the plates. A velocity profile obtained in an activated sludge aeration tank treating pulp and paper mill wastes is shown in Figure 4. The data shown on Figure 4 were obtained by lowering a current meter to the indicated depths. For all of the aeration devices included in these studies the liquid velocities near the surface ranged from 2.0 to 4.0 fps and from 0.5 to 2.0 fps at greater depths.

A traverse made of DO values at various points in the aeration tank described above showed the DO to be substantially constant throughout the tank. It is therefore reasonable to expect that at the turbulence levels encountered in commercial aeration practice no concentration gradient will exist in the aeration tank itself.

Effect of Temperature

The over-all transfer coefficient, K_La, will be affected by changes in operating temperature. Temperature influences the diffusivity of oxygen in water as well as other physical variables in the aeration process. Several formulations have been proposed to define this effect (8) (9). Recent studies by Truesdale and Vandyke (11) indicate a possible variation in temperature effect of 1.0 to 4.5 per cent per degree Centigrade depending on the aeration conditions. From data available at the present time K_La can be expected to increase about 2 per cent for each 1°C rise in temperature.

Effect of Waste Characteristics

Wastes will exhibit variable capacity for mass transfer under defined aeration conditions. The specific cause of the variation in the over-all mass transfer rate has not been established. A reduction in K_L has been attributed to an adsorbed layer of surface active agent at the air-liquid interface which may retard the bubble velocity and surface renewal rate and create a diffusion barrier. The interfacial area for transfer is also influenced by a change in the effective bubble size (7) (10).

In the presence of high concentrations of proteins and certain other organics the observed transfer rate may be greater than the rate in tap water while at low concentrations the rate is less than the tap-water rate. This phenomenon has been observed in studies of pharmaceutical and synthetic fiber wastes.

As bio-oxidation proceeds, and contaminants are destroyed by oxidation, the transfer rate approaches the water value. Typical data obtained from laboratory studies for various industrial wastes are shown in Table IV.

Effect of Defoaming Agents

As a result of the increasing use of defoaming agents in activated sludge plants, the effects of low concentrations of some common agents on the transfer-rate coefficient were studied. Both silicone and oil base defoaming agents were used in these studies. The results, summarized in Table V, were obtained by aeration in a four-liter circular column using an aloxite diffuser stone. Following a nitrogen purge, the increase in dissolved oxygen at various air flows was measured polarographically. The transfer coefficient, K_La, was calculated from the integrated form of Eq. 2. The coefficient, α, was computed as the ratio of K_La in the test solution to K_La in water at the same air flow. The coefficient, α, was independent of air flow in these studies.

TABLE IV.—Summary of Oxygen Transfer Characteristics of Some Industrial Wastes and Their Bio-oxidation Effluents

Waste	BOD		α	
	Influent	Effluent	Influent	Effluent
Paper repulping*	187	50	0.68	0.77
Semi-chemical machine backwater*	1872	—	1.40	—
Mixed Kraft mill	150–300	37–48	0.48–0.86	0.70–1.11
Pulp and paper (bleach plant)†	250‡	30‡	0.83–1.98	0.86–1.0
Pulp and paper (pulp mill)†	205‡	—	0.66–1.29	—
Pharmaceutical	4500	380	1.65–2.15	0.73–0.83
Domestic sewage (fresh)	180	9	0.8	0.98
Synthetic fiber	5400	585	1.88–3.23	1.04–2.65
Board mill	660‡	—	0.53–0.64	—

* Paper repulping and semi-chemical wastes mixed prior to bio-oxidation.
† Bleach plant and pulp mill wastes mixed prior to bio-oxidation.
‡ Average values.

TABLE V.—Effect of Various Anti-foams on the Oxygen-Transfer Coefficient Ratio, α

Anti-foam Type	Anti-foam Concentration (ppm)	Solution*	α	α'†	σ_s/σ_w‡	σ_s/σ_p§
A (silicone base)	5	Water	0.950	—	0.814	—
do	10		0.815	—	0.745	—
B (oil base)	5		0.750	—	0.864	—
do	10		0.700	—	0.765	—
C (oil base)	5		1.050	—	0.831	—
do	10		1.075	—	1.00	—
D (oil base)	5		0.965	—	0.896	—
do	10		1.140	—	0.975	—
do	25		1.140	—	—	—
A (silicone base)	5	500-ppm peptone	0.550	0.880	0.686	0.930
do	25		0.500	0.880	0.651	0.894
B (oil base)	5		0.575	1.00	0.675	0.915
do	10		0.635	1.310	0.686	0.930
do	25		0.475	0.840	—	—
C (oil base)	5		0.590	1.110	0.691	0.936
do	10		0.520	1.130	0.728	0.988
do	25		0.505	0.950	—	—
D (oil base)	5		0.445	0.840	0.730	0.991
do	25		0.470	0.885	0.721	0.980
E (silicone base)	—	Syn.-fiber waste	1.64	0.870	—	—
do	—	Bio-oxidation effl.	1.04	0.53	—	—
do	—	Water	0.65–0.79	—	—	—

* Temp., 25°C.

† $\alpha' = \dfrac{K_La \text{ (mixture)}}{K_La \text{ (500-ppm peptone)}}$.

‡ $\sigma_s/\sigma_w = \dfrac{\text{surface tension (mixture)}}{\text{surface tension (1\% KCl)}}$.

§ $\sigma_s/\sigma_p = \dfrac{\text{surface tension (mixture)}}{\text{surface tension (500-ppm peptone)}}$.

Transfer Rates in Waste Systems

Daily Variation

The oxygen transfer rate in waste treatment systems has been observed to vary from day to day. Cases where more than one set of results was available are indicated in Table IV. This variation can be attributed to changes in the chemical composition of the waste, variation in aeration solids, and variation in the physical characteristics of the aeration system (temperature, pressure, etc.). The variation in relative transfer rate for a combined Kraft mill waste and its bio-oxidation effluent, evaluated over several weeks, is shown in Figure 5. These data were obtained by aeration under standard conditions in a one-liter cylinder. Over a 45-day period, with daily measurements, the variation encountered in the aeration of pulp and paper mill wastes with activated sludge, using spargers, showed that 10 per cent of the time K_La was equal to or less than 3.4, and 90 per cent of the time K_La was equal to or less than 8.0. This variation can be compensated for in practice by maintaining at least 2 ppm DO under average conditions and constant air flow. For the example previously cited, at a 10 per cent frequency level the DO would be 0.5 ppm.

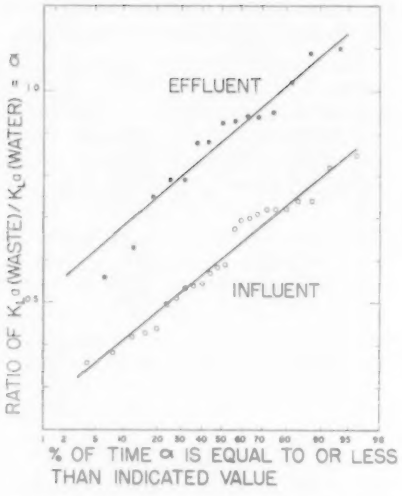

FIGURE 5.—Variation in oxygen transfer rate.

Oxygen Absorption Efficiency

When comparing aeration devices or evaluating absorption in various wastes it is important to consider absorption efficiency. The absorption efficiencies for the units shown in Table I, at near optimum air-flow rates, are shown in Table VI.

From Table VI it can be seen that the absorption efficiency varies with the nature of the waste and the geometry of the aeration tank. For example, 10 per cent oxygen absorption was obtained with a sparger unit emitting 16 cfm in sulfite waste contained in a rectangular tank. At the same air-flow rate the absorption was 8.6 per cent for sewage in a spiral-flow tank. The transfer ratio, α, for this sewage could be expected to range from 0.75 to 0.85. For a pulp and paper waste in a spiral flow aeration tank the absorption was 9.8 per cent. Similar observations can be made for the other types of aeration devices.

TABLE VI.—Oxygen Absorption Efficiency of Aeration Devices

Diffuser Unit	Waste	Depth (ft)	Air Flow (scfm)	Oxygen* Absorption (per cent)
Aloxite tubes	Sulfite	15	6	13.7
Plastic tubes		15	6	10.0
Sparger		15	16	10.0
Impingement		15	12	11.7
Disc-type		13	16	9.8
Sparger†	Sewage	15	16	8.6
Sparger	Pulp & paper	15	16	9.0
Sparger†		15	16	9.8
Disc-type†		15	16	8.6
Jet	Pharmaceutical	4	0.5	24.8

* Zero dissolved oxygen.
† Activated sludge plant.

Measurement of K_La

Necessity

The performance of commercial aeration devices in sulfite-waste oxidation studies has been reported in the literature (3) (7). When tank geometry is similar and data are available on the transfer characteristics of the waste relative to water, the sulfite data may be used for aeration design. In many cases, however, variations in the physical arrangement of the equipment and changes in the chemical nature of the waste necessitate evaluation of the oxygen transfer characteristics under actual operating conditions. The test procedures which may be employed for such a study are summarized below.

Steady-State Aeration—Activated Sludge

In those cases where the waste loading is reasonably constant and the oxygen-uptake rate does not vary markedly with time, the transfer coefficient, K_La, can be evaluated from Eq. 4. The DO in the tank liquor and the oxygen-uptake rate can be measured by polarographic or chemical methods in the field. The saturation value employed in Eq. 4 is computed for the midpoint of the tank depth.

The oxygen-uptake rate is affected by the turbulence level maintained in the aeration tanks. Since the polarographic procedure does not reproduce tank turbulence conditions at high turbulence levels encountered in turbine aeration systems, analysis of the exit gas by an oxygen gas analyzer or Orsat apparatus will more accurately record the uptake rate.

The average uptake rate is obtained by averaging the exit gas content at several points across the surface of the aeration tank.

Non-steady-State Aeration — Activated Sludge

An accurate measure of the transfer coefficient, K_La, can be obtained by a non-steady-state procedure under stabilized operating conditions. When the air is turned off or reduced to a low level in the aeration tanks, the dissolved oxygen will approach zero through microbial respiration. After DO is absent from the system the air rate is returned to its operating level and samples are withdrawn at one-minute intervals for DO measurement. Sampling is continued until a steady-state condition is approached. The oxygen-utilization rate is determined as previously described. The K_La value for the system is computed by a graphical method employing Eq. 3. Tangents are drawn to several points on the curve produced by a plot of DO against time. From these, dc/dt at a corresponding value of DO is computed.

Non-steady-State Aeration

In many cases it is desirable to determine the transfer coefficient, K_La, in aeration tanks without activated sludge. The DO present in the waste water can be removed by adding sodium sulfite to which cobalt has been added as a catalyst. Air is then admitted at the desired level and the DO measured at one- or two-minute intervals after the sulfite is oxidized. The transfer coefficient, K_La, is computed from the slope of a plot of $C_s - C_L$ *vs.* time of aeration. By repeating this procedure for various depths and air rates, the absorption number, N, for the system can be calculated. The data shown in Figure 1 were obtained in this fashion.

Summary and Conclusions

The oxygen-absorption capacities of aeration devices are influenced by: airflow rate, depth of submergence, temperature, and tank turbulence. In the aeration of industrial wastes the rate of absorption will be further influenced by the chemical nature of the waste.

Most wastes exhibit a tendency to reduce the transfer rate as compared with water. A few wastes have been observed to increase the transfer rate, particularly at high waste concentrations. The variations in transfer rate will be reflected by changes in waste characteristics.

The performance of commercial aeration devices and effects of waste characteristics can be correlated in terms of an absorption number. The absorption number can be used for aeration design and operation where operating conditions are the same as test conditions.

Acknowledgment

This study was supported in part by a research grant of the National Institutes of Health, U. S. Public Health Service.

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APPENDIX—LIST OF SYMBOLS

A = Interfacial area for transfer;
a = Ratio of interfacial area to liquid volume;
α = Transfer ratio; ratio of K_La of test solution to K_La of water;
$\beta, \beta_1, \beta_2, \beta_3, \beta_4$ = constants;
C_L = Dissolved oxygen concentration in the liquid;
C_s = Saturation of oxygen in water or waste at mean depth and average oxygen concentration in the gas phase;
d_b = Mean diameter of air bubble;
G_s = Air flow;
h = Tank liquid depth;
K_L = Over-all liquid-film coefficient;
K_La = Over-all oxygen-transfer coefficient;
m = Depth exponent;
n = Gas rate exponent;
N = Absorption number;
N_s = Peripheral speed;
ϕ, ϕ' = Exponents;
R = Mass transfer rate;
r_r = Oxygen-uptake rate;
S_c = Schmidt Number; ratio of kinematic viscosity to diffusivity coefficient;
V = Volume of liquid under aeration;
V_s = Superficial air velocity;
v_b = Velocity of air bubble relative to tank liquid;
x, x', x'' = Exponents.

DUES FOR THE NEW YEAR

To assure continuous receipt of SEWAGE AND INDUSTRIAL WASTES the membership is urged to make immediate payment of 1959 dues to the appropriate Member Association Secretary. The January 1959 issue of the Journal will be the last one mailed to those from whom payment is not in the Federation office by February 6.

Your attention is also drawn to the method of handling payment. Sufficient time must be allowed for the Member Association Secretary to process and mail the dues information to the Federation office which, in turn, must have time to notify the printer for mailing purposes. If a member is removed from the mailing list, it then becomes a costly, time-consuming, and cumbersome task to make reinstatement after late payment of dues.

Your Member Association Secretary is listed on page 6a of this issue.

Stream Pollution

ACTIVITIES OF THE INTERNATIONAL JOINT COMMISSION, UNITED STATES AND CANADA*

By Eugene W. Weber

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In this presentation on the activities of the International Joint Commission, it is the intention to describe briefly the origin and purpose of the Commission and to outline its duties and current activities, pointing out particularly those aspects of the work related to air and water pollution. The pollution problems are of particular significance in the Detroit area and in the connecting channels of the Great Lakes generally.

Briefly, the International Joint Commission, United States and Canada, consists of three representatives from each country charged with the duty of carrying out the purposes of the Boundary Waters Treaty of 1909 through the exercise of certain delegated powers and through the conduct of investigations and studies leading to recommendations for action by the two Governments.

Background

The Treaty of 1909 had its origin at the turn of the century when it became increasingly apparent to interests in both countries that there was need for improved procedures for settling the problems that had already arisen and the additional problems that could be expected to arise in the future regarding the use of waters flowing along and across the boundary and into and out of boundary waters. There are more than 3,000 miles of boundary between Canada and the United States from the Atlantic to the Pacific, and some 2,000 miles between Alaska and Canada.

The 1909 Treaty was negotiated and entered into pursuant to recommendations of a temporary International Waterways Commission which analyzed the current and possible future problems along the boundary and recommended a permanent organization to deal with them. The Treaty declares it to be the purpose and desire of the Contracting Parties:

> To prevent disputes regarding the use of boundary waters and to settle all questions which are now pending between the United States and the Dominion of Canada involving the rights, obligations, or interests of either . . . along their common frontier, and to make provision for the adjustment and settlement of all such questions as may hereafter arise, ...

The current membership of the permanent six-member Commission created by the Treaty is composed of three members from each country. These are, for Canada: General A. G. L. McNaughton, Chairman; Mr. J. Lucien Dansereau, Quebec; and Dr. D. M. Stephens, Manitoba; and for the United States: The Honorable Douglas

* Presented at the 31st Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Detroit, Mich.; Oct. 6–9, 1958.

McKay, Chairman; Mr. Francis L. Adams; and Mr. Eugene W. Weber.

Responsibilities

The Commission's responsibilities fall into two general categories: (a) the duty of approving or rejecting applications for various types of works in boundary waters or waters crossing the boundary that would have the effect of raising water levels at the boundary; and (b) performing the function of investigating and making recommendations to the Governments of Canada and the United States on specific problems along the boundary whenever the two Governments so request.

The first category covers applications which may be made by individuals or public or private agencies for works in either country designed to utilize, obstruct, or divert boundary waters whenever such works would affect the natural level or flow of boundary waters on the other side of the line. An example of this type of situation is the St. Lawrence Power Project.

Similarly, works designed for the use, obstruction, or diversion of waters flowing out of boundary waters or waters after they have crossed the boundary that would have the effect of raising water levels at the boundary also require approval of the International Joint Commission. An example of the latter type of situation is the proposed Libby project on the Kootenai River in Montana. This is currently before the Commission.

The procedure involved in either of the foregoing situations calls for submission of an application to the Commission by either Government or by individuals or agencies through their Government. This is to ensure that the application is in conformance with any requirements of the Government within its own jurisdiction. In the case of works involving both countries, such as the St. Lawrence Project, the usual practice is for parallel applications to be submitted.

Upon receipt of an application, the Commission notifies all concerned and arranges for public hearings and other opportunities for the Governments or other interests to file formal statements. After consideration of the representations of all concerned, the Commission is charged by the Treaty with the duty of issuing an Order of Approval for those applications found to be acceptable and of ensuring in its Order of Approval compliance with certain principles and protection and indemnification against injury of any interests affected by the project. Among the major principles to be observed are that each Government shall have equal and similar rights in the use of boundary waters and that the following order of preference shall be observed:

1. Uses for domestic and sanitary purposes.
2. Uses for navigation.
3. Uses for power and irrigation.

The second general category of the Commission's duties is that of making investigations and studies of specific problems when requested to do so by the Governments. Under Article IX the Commission may be requested to study and make recommendations on a question by either Government. This feature of the Treaty has often been utilized.

Under Article X of the Treaty, the Commission may be requested to examine into and report upon a problem and to render a decision or finding upon the matter which will be binding upon the parties providing both Governments have agreed in advance to refer the question on that basis. This provision of the Treaty has not yet been utilized by the two Governments.

Recent Considerations

Among the more recent and current activities of the Commission are: (a)

the comprehensive studies of possible development of the Columbia River Basin, principally involving hydroelectric power projects, (b) studies of several situations from the Continental Divide to the Red River of the North, involving principally the apportionment of waters utilized for irrigation and other consumptive uses, (c) the Lake of the Woods watershed including Rainy Lake and the Northwestern Chain of Lakes, where levels of the waters are of importance from both power and recreational standpoints, and where the pollution problem has recently arisen, (d) the Great Lakes-St. Lawrence System where lake levels, navigation, water supply, pollution problems, the preservation of Niagara Falls, and the St. Lawrence Seaway and Power Projects have been studied, and (e) the St. Croix and St. John River basins in the Northeast and the possibilities of developing power from the tides at Passamaquoddy.

Pollution Problems and Studies

Of these activities the air and water pollution problems are important segments.

The studies of air pollution under the jurisdiction of the Commission had their origin primarily in the problem of smoke from vessels traversing the international waters past Detroit and Windsor. Study was also given, however, to the problem of air pollution from land sources, but the report which the Commission hopes to submit to the two Governments in the near future will be aimed primarily toward the establishment of procedures to permit effective control of the emission of smoke from vessels using these international waters.

With respect to water pollution, the Boundary Waters Treaty of 1909 stipulated that boundary waters and waters flowing across the boundary between Canada and the United States should not be polluted on either side to the injury of health or property on the other side. The Treaty did not designate specific procedures to ensure compliance with this agreement. Accordingly, water pollution problems have been handled under the general provisions of Article IX, under which considerations of any kind can be referred to the Commission for investigation, report, and recommendation.

The first studies of the water pollution problem pursuant to the Treaty were undertaken by the Commission at the request of the two Governments in 1913. After examination of the problem along all boundary waters the Commission's report to the two Governments recommended specific remedial measures, but the outbreak of World War I and later events precluded normal consideration of the report, with the result that the Governments did not take joint or coordinated action on the Commission's recommendations.

In April 1946 the two Governments again asked the Commission to study the pollution problem, requesting the study of specific areas encompassing essentially the connecting channels of the Great Lakes from Sault Ste. Marie to the Niagara River.

One of the first steps under the 1946 reference was the appointment by the Commission of a board of sanitary experts to act as technical advisers. The board appointed for the connecting waters of Lakes Superior, Huron, Erie, and St. Clair included representatives from the Federal health agencies of the United States and Canada, as well as representatives of the State of Michigan and the Province of Ontario. A similar board for the Niagara area included similar Federal representatives as well as representatives from the State of New York and the Province of Ontario.

Recommendations

After exhaustive investigations over a period of three years, including field surveys, laboratory analyses, and office

studies, the Commission received a comprehensive report from its board of advisers in 1950 and submitted recommendations to the Governments of Canada and the United States for adoption of Objectives for Boundary Waters Quality Control that would, in general, provide that all wastes, including sanitary sewage, storm water, and industrial effluents, shall be in such condition when discharged into any stream that they will not create conditions in boundary waters which will adversely affect the use of those waters for the following purposes: (a) source of domestic water supply or industrial water supply, (b) navigation, (c) fish and wildlife, (d) bathing, (e) recreation, (f) agriculture, and (g) other riparian activities. The Commission also recommended that it be specifically authorized by the two Governments to establish and maintain continuing supervision over boundary waters pollution through boards of control.

Advisory Boards

The two Governments approved the Commission's recommendations in 1951 and shortly thereafter the Commission appointed advisory boards on the control of pollution of boundary waters with representation similar to that originally adopted for the boards of experts who advised the Commission in the investigation stage. These boards have been active since 1952 in following up on the specific pollution problems delineated in the original report of the Commission and in advising the Commission on all matters pertinent to realization of the objectives for control of boundary waters quality in accordance with the intent of the Treaty.

The members of the boards are, for Canada: J. Ross Menzies, Chairman, and W. R. Edmonds, Department of National Health and Welfare; A. E. Berry and A. V. Delaporte, Ontario Water Resources Commission, Province of Ontario; and for the United States: L. F. Warrick, Chairman, and H. H. Black, U. S. Public Health Service; L. F. Oeming, Water Resources Commission and W. F. Shephard, State Department of Health—State of Michigan—serving on the board for Lakes Superior, Huron, and Erie; and Earl Devendorf, State Department of Health, and A. F. Dappert, State Water Pollution Control Board—State of New York—serving on the board for Lakes Erie and Ontario.

Current Activities

Since 1952, the pollution abatement activities in these international waters have been carried out under the guidance of the Commission's Advisory Boards and with the aid of the U. S. Public Health Service. In close collaboration with the States, the Public Health Service maintains field units in Detroit and Buffalo for the U. S. Section; and the National and Provincial Health Agencies provide field services for the Canadian Section of the Commission. The field activities include collection of basic water quality data, studies of transboundary travel of pollution, determination of improvements effected by municipal and industrial waste treatment, assembly of data on water uses, application of new analytical techniques (carbon filter, bioassay, etc.) in boundary water pollution control investigations, and other work involved in providing information to assist the Commission in carrying out its functions relating to boundary water quality.

The International Joint Commission and its Advisory Boards meet at least twice each year to review progress being made, to indicate where needs exist for putting remedial measures in effect for control of pollution, and to see that such findings are brought to the attention of the proper water pollution control agencies for appropriate action. The Commission is exerting its influence to the fullest

FIGURE 1.—Stream pollution of boundary waters between the United States and Canada.

extent to expedite the installation of sewage and industrial waste treatment works and other improvements to abate pollution of the boundary waters.

The types of pollutional materials discharged to the boundary waters include untreated and partially treated domestic sewage, industrial wastes, intermittent release of sewage from both freight and passenger vessels, and the leaching from dredge dumps. In addition, there are numerous overflows

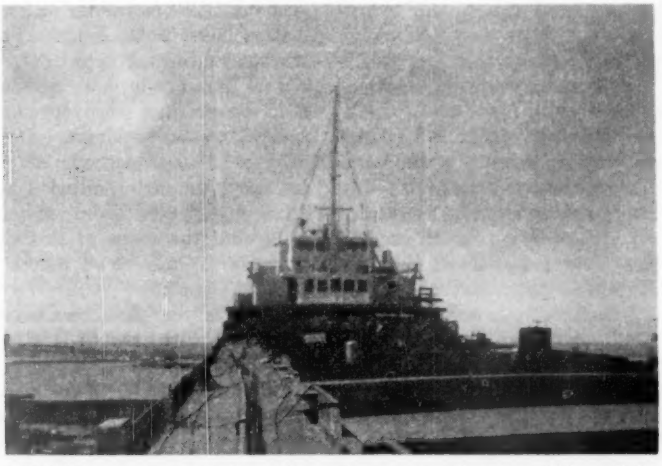

FIGURE 2.—Great Lakes ship under construction in which a light system of sewage treatment is being installed.

FIGURE 3.—Oil removal plant at Ford Motor Company, Detroit, Mich.

from combined sewers and irregular discharges from tributaries which bring accumulations of pollutional materials into the main streams. During periods of excessive runoff, the flushing of sewers and overflows introduce a significant additional pollution load on the boundary waters. An example of the pollution problem is shown in Figure 1. Figure 2 shows the new construction of a Great Lakes vessel in which sewage treatment facilities are being built.

An international system for warning downstream water users following industrial waste spills has been established. Cooperative working relations are maintained with State and Provincial water regulatory agencies. Representations made as a result of the Commission's activities are believed to have been an important factor in the recent enactment of legislation which created the Ontario Water Resources Commission and which provides means for financing, constructing, and operating sewage treatment works in the Province of Ontario.

In addition to municipal sewage treatment problems, many of which also involve disposal of wastes from manufacturing plants, there is a wide variety of industrial effluents entering the boundary waters. The wastes are from such industrial manufacturing operations as pulp and paper, synthetic organic chemicals, electrochemicals, petroleum refining, automobiles, iron and steel, by-product coke, synthetic fiber, petro-chemicals, rubber, electrometallurgical, textiles, and many others.

Larger industries have, for the most part, elected to solve their waste problems independently through process control and separate waste treatment systems. The character and volume of wastes have dictated this approach in several cases and in others municipal sewers have not been accessible. Profitable by-product recovery has solved several waste problems. Descriptions of the various methods employed by industry to curb pollution would require a series of technical papers and is beyond the scope of this discussion. However, it may be of interest to cite a specific example.

About a year ago the Commission in company with the Advisory Boards visited a by-product coke plant in the Buffalo area. To abate pollution of the boundary waters the company had completed a few months before the visit an ultra-modern phenol removal plant at a cost of more than $150,000.

The new dephenolizing tower was designed to remove about 95 per cent of the phenol in the wastes. Results of cooperative studies subsequent to the visit have shown that the design efficiency was exceeded. During the period of the studies the phenol recovery unit removed about 1,500 lb of phenol daily, which was 99 per cent of the phenols in the ammoniacal liquor. Bioassays revealed that the dephenolization process removed two-thirds of the toxicity of the ammoniacal liquor. During and since the original construction of its coke plant the company has spent about $450,000 in plant equipment and research to eliminate pollution at its plant.

Installations of oil separators as well as biological treatment for refinery wastes, oil and solids removal facilities at automotive plants (Figure 3), iron and steel, and other manufacturing plants, and a variety of other systems for taking care of pollutants have been provided. Principles and practices for minimizing wastes at their source, or even changing of processes to avoid pollutional wastes, have been utilized in the boundary water cleanup program, and are being advocated for use in connection with new industrial projects.

Summary

In general, it may be stated that the progress since adoption of the Commission's recommendations in 1952 has been gratifying. A quantitative appraisal of the progress and of the current situation in boundary waters is under way and will be made available to interested parties by the Commission when it is completed in 1959.

In conclusion, it is desired to point out that the activities of the International Joint Commission in the interests of abatement of water and air pollution have been carried out within the framework of previously established authority and responsibility at Federal and non-Federal levels. The necessary surveys and studies have been accomplished by the agencies who normally have such responsibilities within their respective jurisdictions. The implementation of remedial measures has also been accomplished under the aegis of those agencies. The International Joint Commission has merely provided the machinery for bringing their efforts to bear on the problems in concert and to work toward common and mutually acceptable objectives. In addition to support of State, Provincial, and local agencies, it is also emphasized that there has been wholehearted cooperation of business and industry generally, both in analyzing the problems and in applying corrective and preventive measures where needed. This has been most important and is essential to success in the solution of the pollution problems.

STREAM DATA CLASSIC

The Public Health Service has reprinted and is making available from the Robert A. Taft Sanitary Engineering Center, 4676 Columbia Parkway, Cincinnati, Ohio, the classical studies by Streeter and Phelps presenting the basic mathematical formulation of the oxygen-sag equation. This fundamental treatise has long been out of print.

The complete reference is: Streeter, H. W., and Phelps, E. B., "A Study of the Pollution and Natural Purification of the Ohio River. III. Factors Concerned in the Phenomena of Oxidation and Reaeration." Public Health Service Bulletin No. 146 (Feb. 1925), Reprinted by the U. S. Dept. of Health, Education, and Welfare, Public Health Service (1958).

STUDIES ON THE USE OF MEMBRANE FILTERS FOR THE ESTIMATION OF COLIFORM DENSITIES IN SEA WATER

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In the Orange Co. laboratory the use of membrane filters for the estimation of coliform densities in sea water was begun during July 1956. After two months of use in parallel with the fermentation tube procedure (confirmed test) (1), the use of this latter method was discontinued except for those samples of surf water which are reported to the various regulatory agencies. Parallel testing results of a large number of samples by the fermentation tube procedure and the membrane filter method have been covered by earlier progress reports (2)(3)(4).

From the beginning it was evident that the membrane filter method did not give exactly the same results as the fermentation tube test, but even a casual inspection of the results of parallel tests on a rather large number of samples led to the conclusion that both methods gave substantially the same information. Hence it was decided to use the membrane filter method for a large proportion of the samples on account of the many practical advantages, and to make further studies to determine, if possible, the relationship between the results obtained by the two methods.

The practical advantages to be gained by the use of the filter procedure are: (a) reduction in time required for the preparation of culture media and glassware, (b) earlier availability of results, (c) saving in incubator space, and (d) reduction in time required for all operations in inoculating, reading, and transplanting cultures.

The net result is that the capacity of the laboratory, in terms of samples per day, can be increased three- or four-fold, with no increase in man-hours expended, incubator space, or quantities of media, and with a smaller investment in glassware and other materials. Results have indicated that the time required per sample is between one-fourth and one-third of that required for the fermentation tube test. It is not so easy to estimate the saving in time for the preparation of media and glassware, but it is obvious that it is both easier and quicker to wash one or two Petri dishes than 20 culture tubes.

Thus, accepting the filter technique for certain classes of routine work on the bases of results obtained in other laboratories as well as the comparative work previously reported from this laboratory, a program was undertaken to study the accuracy and precision of both the membrane filter and fermentation tube methods. It is the purpose of this report to record the results of that program.

Procedures

In the examination of surf-water samples this laboratory uses the standard fermentation tube (confirmed) test. The original inoculation is made in lactose broth, using 5 tubes with 10 ml of sample, 5 tubes with 1.0 ml, 5 tubes with 0.1 ml, and 5 tubes with 0.01 ml. All positive tubes represent-

ing 1.0 ml or less are transplanted to brilliant green bile (BGB) for confirmation. All dilutions are made with buffered dilution water. Difco dehydrated lactose broth and brilliant green bile are used. Results are reported as the most probable number of coliform organisms per ml (MPN) using a table developed by expansion of the table in "Standard Methods" (1).

For the membrane filter procedure, Difco dehydrated M-Endo-MF broth is used. This medium is used in a one-step procedure, without enrichment. The filters are Type HA, 47 mm.* Where dilutions are required, sterile buffered dilution water is used. The same water is used for rinsing the filters after filtration of the sample is completed. When portions 10 ml or larger are used for filtration, the sample is pipetted directly into approximately 30 ml of sterile dilution water in the filter holder. Filter holders are not sterilized, as experience here and in other laboratories has shown this to be unnecessary as long as the equipment is thoroughly rinsed with sterile water between samples. Minor variations in the pads affect the volume of medium required, but it is usually 1.9 to 2.0 ml. Filters and pads are incubated in Petri dishes inverted and covered in an ordinary incubator. No difficulty has been experienced with lack of humidity when covered Petri dishes are used, and experiments have shown that excessive moisture tends to cause spreading growths.

Colonies on the filters are counted after 18 to 20 hr of incubation, using a binocular microscope with 1.33 × objectives and 10 × eyepieces. The number of sheen colonies per filter is recorded according to the following schedule: (a) For 50 colonies or less, record exact number. (b) For 51–100 colonies, record to nearest 5. (c) For 101 or more colonies, record to two significant figures. The number of non-coliform colonies per filter is also recorded on the work sheet, generally estimated to two significant figures, to give an idea of whether the coliform count may have been affected by crowding. Results are reported as membrane filter count (MFC) per ml.

* Manufactured by the Millipore Filter Corp., Watertown 72, Mass.

Replicate Testing

Surf Water

During two periods of approximately three weeks each, the work load on the laboratory made it practical to use both membrane filter and fermentation tube procedures on all samples of surf water. During the period June 17 to July 5, 1957, a total of 336 samples was examined; during the period September 10 to October 1, 1957, 359 samples were run. The results of these 695 samples were analyzed statistically. For part of the statistical work the results of the two groups were kept separate.

The first step in the comparison of the results of the two procedures was to make log-probability plots of the results, following the procedure of Thomas (5). The results are shown in Figures 1 and 2. The theoretical line of best fit was determined from the geometric mean and the geometric standard deviation (Table I).

It will be noted that deviation of the plotted points from the theoretical line is less for the MFC values than for the MPN values, and that at the higher values the deviation of the MPN becomes more severe. It is ob-

TABLE I.—Values of the Geometric Mean and Geometric Standard Deviation for Surf-Water Samples

Statistical Parameter	Group 1		Group 2	
	MPN	MFC	MPN	MFC
Geometric mean	0.38	0.16	0.58	0.12
Geometric standard deviation	6.9	4.6	8.6	5.8

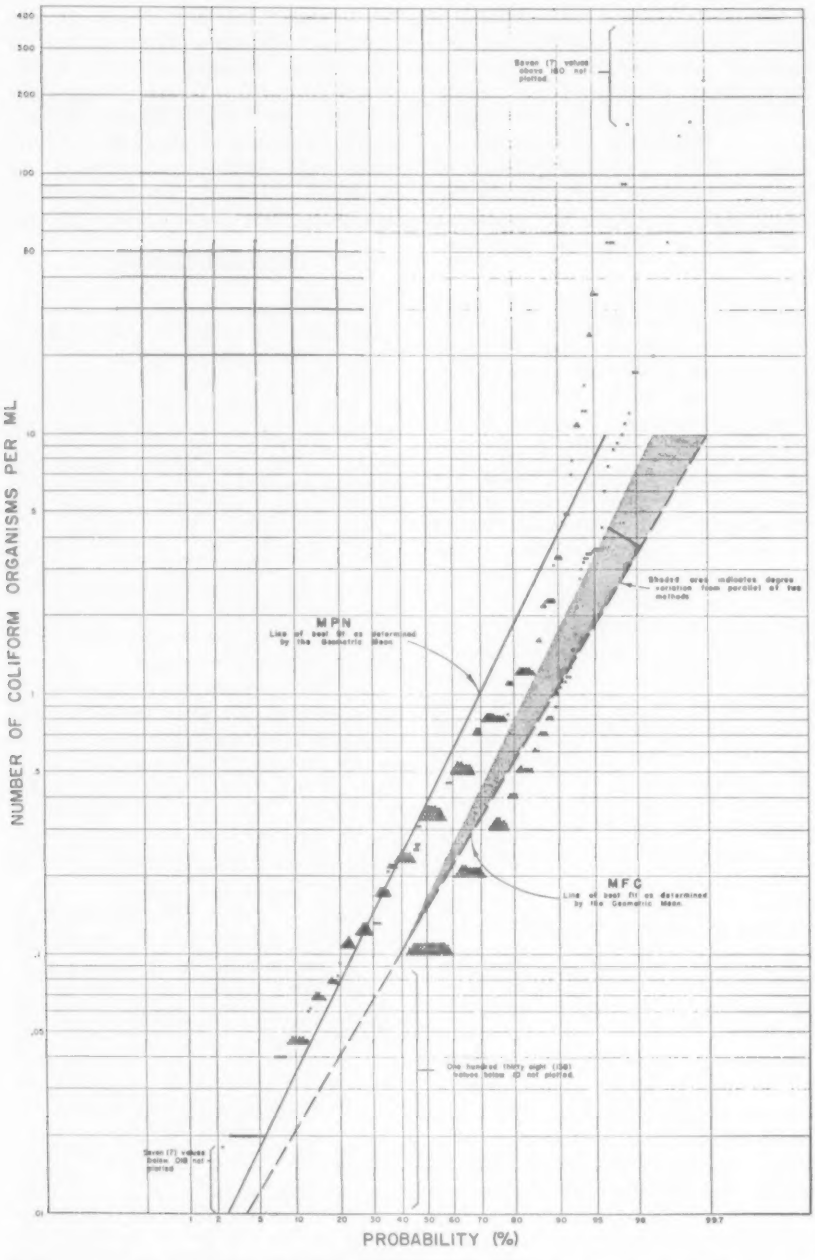

FIGURE 1.—Log-probability plot of MPN and MFC values for a group of 336 samples of surf water collected from June 17 to July 5, 1957.

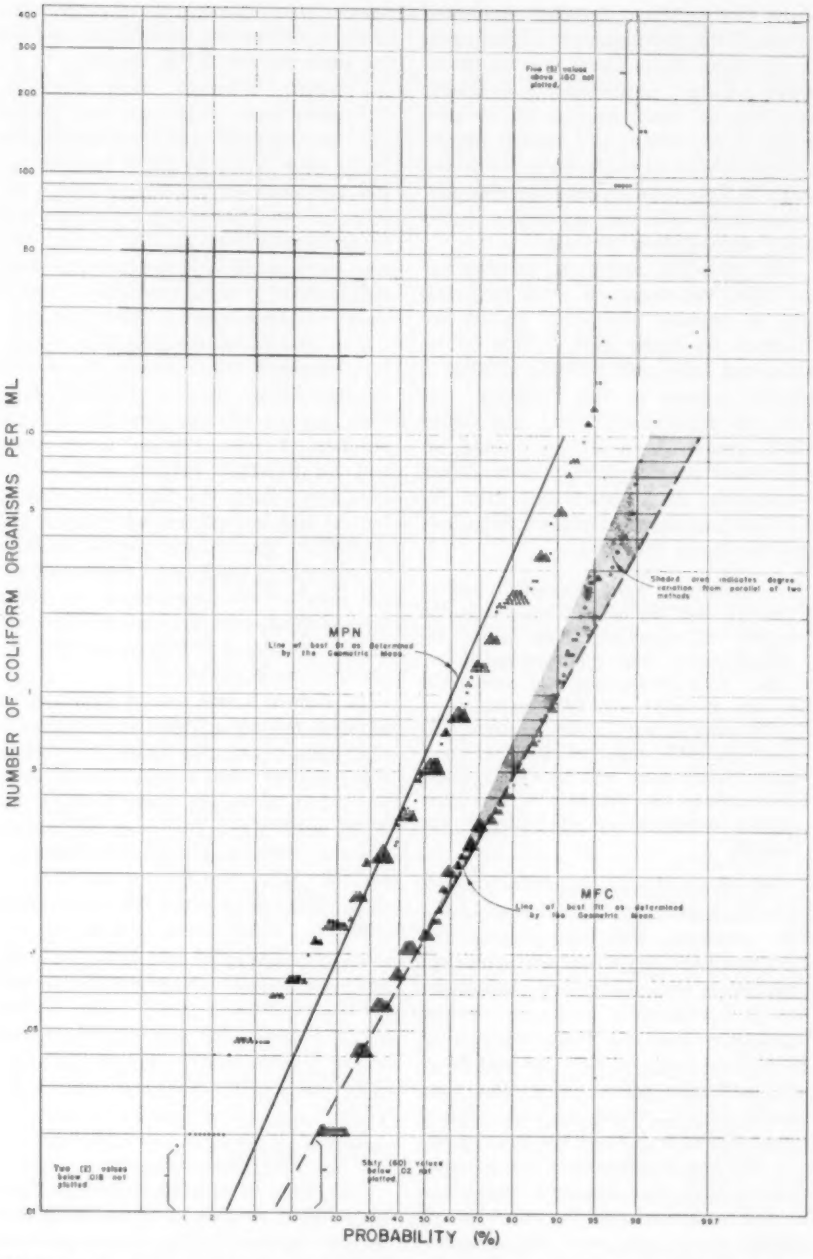
NUMBER OF COLIFORM ORGANISMS PER ML
PROBABILITY (%)
MPN
MFC
Shaded area indicates degree of deviation from parallel of two methods

FIGURE 2.—Log-probability plot of MPN and MFC values for a group of 359 samples of surf water collected from Sept. 10 to Oct. 1, 1957.

vious that coliform densities estimated by the MPN technique are higher, generally, than those based on the membrane filter procedure. Coliform densities in both groups of samples were, on the whole, low, and it can be said that both methods gave about the same information regarding the distribution of coliform organisms in the water during both periods.

The question arises as to whether the MFC values are in error by being low, or whether the MPN values are in error by being high. Data to be presented later will provide at least a partial answer to this question. It must be remembered that the entire MPN system is a device, based on theoretical considerations, to facilitate translation of fermentation tube results into numbers. Prescott, Winslow, and McCrady (6) state:

> . . . A single most probable number (MPN) per 100 ml. of sample is the density of organisms most likely responsible for that combination of results. This density may not correspond to the density actually present in a given sample, but in the long run the most probable numbers will represent more closely than will any other series of numbers the densities of gas producing organisms in the samples examined.

It was probably an inevitable result that the continued use of most probable numbers, the manipulation of these numbers in various mathematical procedures, and the use of such numbers in establishing limits in various regulations has led most workers in the field to think of them as real numbers, actually representing the true density of organisms present. When the empirical nature of the most probable number is considered, it becomes obvious that the standard procedure for the confirmed test for coliform organisms does not meet the requirements of a referee method, and cannot be used as the sole criterion for judging an alternate method. Little is proved when the results of a different coliform-estimating procedure are not the same as the MPN results.

Prescott, Winslow, and McCrady (6) quote from Halvorson and Ziegler (7) that the 97 per cent confidence limits of a five-tube MPN are 30 and 360 per cent of the true value. Results of tests involving replicates will be presented later in this report, and may now be said to confirm this lack of precision of most probable numbers based on fermentation tube results.

The system of most probable numbers, derived from purely theoretical considerations, has a built-in bias. The amount of bias depends on the number of fermentation tubes used, and for five-tube results, such as are considered here, the factor for correction of bias is reported by Thomas (5) as 0.851. The results plotted in Figures 1 and 2 have not been corrected for bias. This bias should be taken into account, and in some of the work to be presented later correction for bias has been made.

In Figure 3 the results obtained by parallel testing of the two groups of surf-water samples are compared. Here all of the samples have been plotted in a log-log plot, showing the MPN and MFC for each individual sample. Obviously, all indeterminate results (MPN less than 0.018 or more than 160, MFC of 0) have been omitted. This leaves a total of 481 samples. The solid line represents the locus of points for which MPN and MFC are exactly equal. The dashed line is the same locus corrected for bias of the MPN. Again, it is obvious that the MPN is generally higher than the MFC.

Diluted Sewage

The data presented thus far have been based on the results of examination of samples taken in actual control work and most of the samples have showed very low coliform densities. This makes the data somewhat

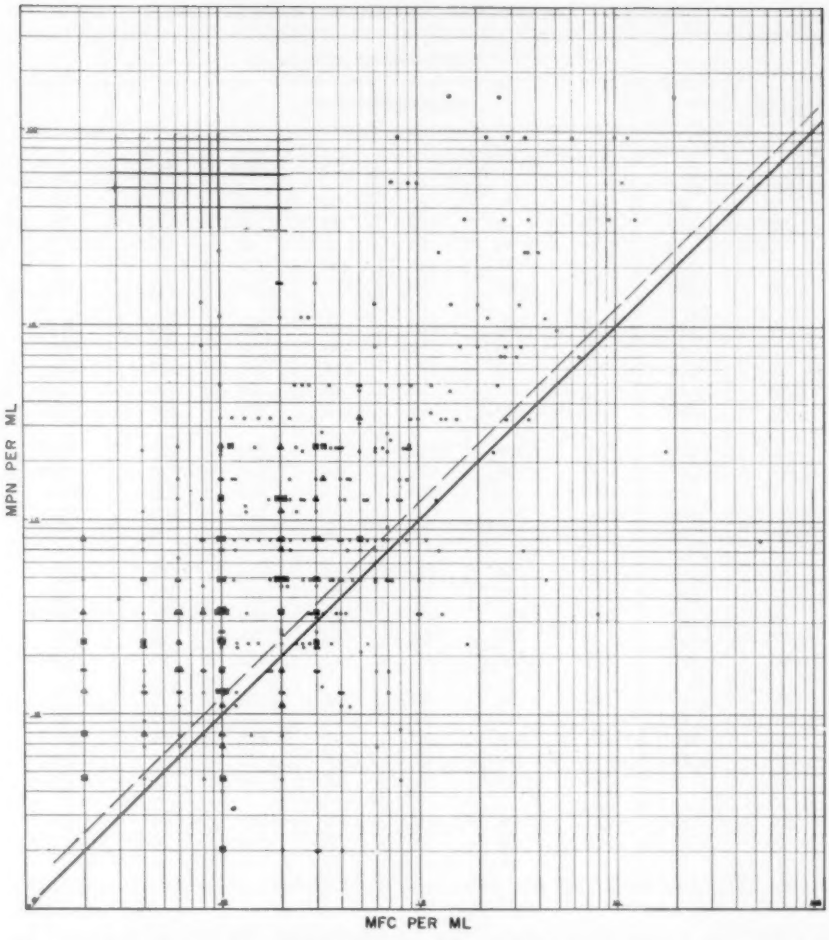

FIGURE 3.—Log-log plot of MPN and MFC values. Solid line represents locus of points for which MPN and MFC are equal; dashed line is same locus corrected for MPN bias.

unsuitable for providing a firm basis for comparison of the MPN and membrane filter methods. It was believed that more conclusive evidence could be obtained by examining samples containing higher concentrations of coliform organisms.

Consequently, a series of 28 tests was run, using settled sewage which had been strained through cotton and diluted to a degree which could be expected to give coliform densities of a few hundred per milliliter. Buffered dilution water, sea water, and unchlorinated well water were used for dilution. No effect attributable to dilution water was noted. Dilutions were made in sufficient volume (usually 1,000 ml) to permit replicate testing.

The general procedure was to determine the MPN in quintuplicate, using five tubes per dilution and usually four dilutions, and to determine

TABLE II.—Replicate MPN Determinations on Settled Sewage

Run No.	Coliform Density (MPN per ml)							
	5-tube MPN							25-tube MPN
	MPN Replicate Results					Arith. Mean	Geom. Mean	
1	24	49	24	17	79	39	33	23
2	92	35	35	17	22	40	34	29
3	49	24	49	79	33	47	43	39
4	54	54	35	240	240	125	90	88
5	130	70	240	79	130	130	117	68
6	240	170	240	240	240	226	224	235
7	49	70	240	49	130	108	98	95
8	130	130	350	350	540	344	313	330
9	49	49	33	79	79	58	55	56
10	350	79	240	350	240	251	223	222
11	170	540	220	170	350	290	261	250
12	110	130	130	130	130	126	126	141
13	920	350	79	130	130	322	212	200
14	350	240	240	170	79	216	193	201
15	79	49	130	79	240	115	99	109
16	140	240	130	130	170	162	157	157
17	240	350	540	350	170	330	306	280
18	350	170	450	350	350	314	303	280
19	130	79	79	110	79	95	93	105
20	540	350	920	350	350	502	463	412
21	17	49	33	49	23	34	31	26
22	49	49	33	79	49	52	50	49
23	240	170	130	130	240	182	175	191
24	35	13	24	22	17	22	21	22
25	13	33	23	17	22	22	21	22
26	110	220	70	79	33	102	84	94
30	13	14	13	11	7	12	11	12
31	11	13	4.9	7.9	13	10	9	9

the MFC in quintuplicate, using two or three different volumes for filtration. In addition the 25-tube MPN was determined. From the replicate-test data the arithmetic and geometric means, standard deviations, and coefficients of variation were calculated. The results of this series of tests are presented in Tables II, III, and IV.

The 25-tube MPN was calculated by the approximate method developed by McKee (8) based on the work of Fair and Geyer (9), and in some cases by the use of the tables of factors of Prescott *et al.* (6). The approximate method is somewhat empirical, and the use of the tables of factors is laborious. The factor for correction of bias for the 25-tube MPN is 0.97. It will be noted that the 25-tube MPN is generally rather close to the geometric mean of the 5-tube MPN values. Consequently, if the 25-tube MPN is accepted as being a nearer approach to the true density than an MPN based on a smaller number of tubes, then the better agreement of the geometric mean of a series of 5-tube MPN values with the 25-tube MPN indicates that the geometric mean should be used to express the results of a series

TABLE III.—Replicate MFC Determinations on Settled Sewage

Run No.	Coliform Density (MFC per ml)						
	Replicate Results					Arith. Mean	Geom. Mean
1	5.4	5.2	2.7	5.5	2.3	4.2	3.9
2	59	130	41	43	22	59	50
3	26	23	30	18	14	22	21
4	80	70	99	72	61	76	75
5	120	110	50	100	110	98	94
6	300	120	135	150	90	159	145
7	125	100	50	60	60	79	74
8	70	90	97	73	65	79	78
9	46	47	40	49	36	44	43
10	53	60	80	120	80	79	75
11	76	180	62	96	60	95	87
12	53	50	50	50	32	47	46
13	102	110	90	110	90	100	100
14	100	60	80	70	80	78	77
15	60	47	50	90	40	57	55
16	90	80	100	52	67	78	76
17	130	120	110	80	100	108	106
18	110	130	110	170	110	126	124
19	88	80	87	63	70	78	77
20	100	110	150	180	150	138	135
21	31	26	21	28	31	27	27
22	41	56	42	34	43	43	43
23	30	35	27	34	37	33	33
24	19	20	20	14	13	17	17
25	5	6	4	12	3	6	5
26	120	120	90	110	120	112	111
30	7	8	5	7	8	7	7
31	9	10	6	9	9	9	9

of tests. This is in agreement with Garber (10).

Comparison of the coefficients of variation shows the better precision of the membrane filter procedure. The lower the coefficient of variation, the better the central tendency of the results. In this series, 16, or 57 per cent, of the tests by the membrane filter method gave a coefficient of variation of less than 0.25, while only 5, or 18 per cent, of the fermentation tube tests gave a value of less than 0.25. In only four experiments did the membrane filter results show a larger coefficient of variation than the MPN procedure. When it is considered that the membrane filter procedure has many of the characteristics of the standard plate count, which has been shown to be capable of high precision, it appears that the filter method might reasonably be expected to show similar precision.

That the failure of the MPN and MFC to give closer results is caused by the extreme variability of the MPN is further indicated by the comparison in Table V, where individual MPN values (after correction for bias) are compared with the geometric mean * of the MFC values.

* Because of the small variation of the MFC results it was felt that the geometric mean could be used legitimately for comparative purposes.

TABLE IV.—Comparison of Standard Deviations and Coefficients of Variation of MPN and MFC in Replicate Testing of Settled Sewage

Run No.	Standard Deviation		Coefficient of Variation	
	MPN	MFC	MPN	MFC
1	25.7	1.6	0.67	0.38
2	30.8	35.3	0.75	0.60
3	20.9	6.3	0.45	0.28
4	106	16.7	0.85	0.22
5	68	27.7	0.52	0.28
6	31.3	81.8	0.14	0.51
7	81.1	32.1	0.75	0.41
8	145	29.8	0.42	0.38
9	20.4	5.4	0.35	0.12
10	111	26.1	0.44	0.33
11	157	49.7	0.54	0.52
12	8.9	8.5	0.07	0.28
13	350	10.0	1.09	0.10
14	31.6	14.8	0.15	0.19
15	75	19.6	0.65	0.34
16	44.6	18.9	0.29	0.24
17	141	19.2	0.43	0.18
18	80.5	26.1	0.26	0.21
19	23.5	10.8	0.25	0.14
20	248	32.7	0.49	0.24
21	14.7	4.2	0.43	0.15
22	16.7	8.0	0.32	0.18
23	55.3	3.8	0.30	0.12
24	8.4	3.4	0.38	0.20
25	8.2	3.5	0.38	0.58
26	71.3	13.9	0.70	0.12
30	2.8	1.2	0.24	0.17
31	3.5	1.5	0.35	0.17

These data have been compared in another way in Figure 4. Here the ranges of the MPN values (not corrected for bias) and the geometric means for the 28 runs have been plotted. It will be noted that the geometric mean of the MFC falls within the range of the MPN values in 12 of the 28 cases, and very close to the range in 6 cases, thus showing reasonable agreement in 18 of the 28 experiments.

The work up to this point seems to demonstrate that the precision of the membrane filter method is superior to that of the fermentation tube procedure. It further shows that when consideration of the variability of the MPN is taken, the two methods at least approach agreement in the majority of cases.

Coliform Cultures

In order to obtain a definite answer to the question of the accuracy of the membrane filter technique, it is necessary to employ an experimental method which allows an approximation of the absolute density of coliform organisms in the sample. Since it is impractical to prepare cultures of known concentration, the usual alternative is to employ pure cultures, so that the total count can be used as an approximation of the absolute density. Up to this point the use of pure cultures had been avoided, since pure cultures do not occur in nature, and the effect of non-coliform organisms would have been absent.

It is not quite correct to refer to the cultures used in this phase of the work as pure cultures. They might better be described as "pure cultures of coliform organisms." Cultures were isolated from either sewage or surf water which were demonstrated to contain only gram-negative, non-spore-forming, lactose-fermenting rods which grew on eosin methylene blue agar with sheen formation. The IMViC series of tests was run on several of these cultures, and did not always give clear differentiation. For the purpose intended, however, such cultures were entirely adequate, since they contained only organisms of the coliform group, even though there might have been more than one strain present.

The experimental procedure was to make a dilution of a 24-hr or younger lactose-broth culture, and to make replicate MPN and MFC determinations on this dilution, as well as replicate total counts. Eight such experiments were run. The results are presented in Tables VI and VII. From these data the following conclusions are drawn:

TABLE V.—Replicate MPN Values Corrected for Bias and Geometric Means of Replicate MFC Values for Samples of Settled Sewage

Run No.	Coliform Density (MPN per ml)					Coliform Density (MFC per ml)
	Replicate 5-tube Value-Corrected					Geom. Mean
1	20	42	20	15	67	3.9
2	30	78	30	15	19	50
3	20	42	42	67	28	21
4	46	46	30	20	20	75
5	110	60	204	67	110	94
6	204	170	204	204	204	145
7	42	60	204	42	110	74
8	110	30	30	30	42	78
9	42	42	28	67	67	43
10	298	67	204	298	204	75
11	145	460	187	145	298	87
12	94	110	110	110	110	46
13	783	298	67	110	110	100
14	298	204	204	145	67	77
15	67	42	110	67	204	55
16	204	110	110	110	145	76
17	204	298	460	298	145	106
18	298	145	298	298	298	124
19	110	67	67	94	67	77
20	460	298	783	298	298	135
21	14	42	28	42	20	27
22	42	42	28	67	42	43
23	204	145	110	110	204	33
24	30	11	20	19	15	17
25	11	28	20	15	19	5
26	94	187	60	67	28	111
30	11	12	11	9.4	5.6	7
31	9.4	11	4.2	6.7	11	9

TABLE VI.—Comparison of MPN, MFC, and Total Count Obtained in Replicate Testing of Coliform Cultures

Run No.	Coliform Density (MPN per ml)			Coliform Density (MFC per ml)		Coliform Density (total count per ml)	
	5-tube MPN		25-tube MPN	Arith. Mean	Geom. Mean	Arith. Mean	Geom. Mean
	Arith. Mean	Geom. Mean					
A	3,980	3,390	3,200	2,160	2,125	2,100	2,050
B	810	570	635	290	288	340	340
C	1,680	1,600	1,730	1,500	1,470	1,250	1,245
D	2,260	2,180	1,940	940	940	950	955
E	2,300	1,890	1,900	930	950	940	940
F	1,190	1,150	1,300	670	670	610	605
G	380	350	310	300	295	295	290
H	73	70	76	58	58	58	58

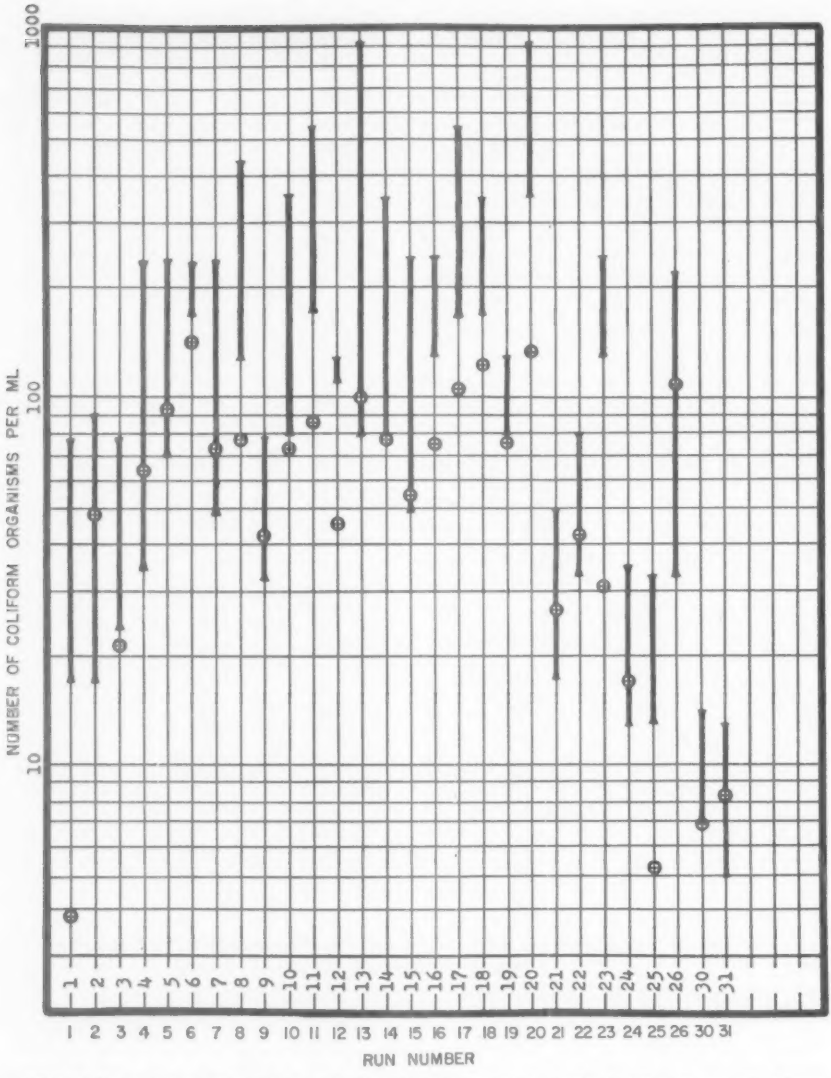

FIGURE 4.—Range of replicate MPN values for settled, strained, diluted sewage shown by solid black line; cross in circle indicates value of geometric mean of replicate MFC results for the same samples.

1. The agreement between MFC and total count results was excellent in six of the eight cases, and reasonably good in the remaining two.

2. The agreement between MPN and MFC results was about the same as for the series of tests on surf water.

3. Agreement between MPN and total count results was reasonably good in two of the eight cases, and fair in one.

4. Coefficients of variation for both MFC and total count results were lower than for the MPN results.

The work up to this point has shown that the membrane filter method is

TABLE VII.—Comparison of Standard Deviations and Coefficients of Variation of MPN, MFC, and Total Count in Replicate Testing of Coliform Cultures

Run No.	Standard Deviation			Coefficient of Variation		
	MPN	MFC	Total Count	MPN	MFC	Total Count
A	2,960	450	410	0.74	0.10	0.19
B	635	33	45	1.10	0.11	0.13
C	1,730	180	60	0.34	0.12	0.05
D	1,940	86	49	0.32	0.09	0.05
E	1,940	96	115	0.78	0.10	0.12
F	1,300	48	55	0.31	0.07	0.09
G	310	23	45	0.13	0.08	0.15
H	76	2.3	4.6	0.35	0.04	0.08

more precise than the fermentation tube method, and in the eight experiments last cited, more accurate. While some of the divergence may be the result of the statistical basis of the most probable number system, experience with both methods indicates that there may be other reasons for the higher results obtained in testing surf-water samples by the fermentation tube method as compared with the membrane filter procedure.

False Positives in the Confirmed Test

Possibly some of the confusion and divergence of opinion regarding the applicability of the membrane filter method for estimating coliform densities in sea water has arisen because it is general practice to use the confirmed test, using brilliant green bile as the confirmatory medium. For the examination of drinking water, the membrane filter method has been accepted as the equivalent of the confirmed test.

While action by the U. S. Public Health Service (11) and the American Water Works Association (12) was based on the method included as tentative in the 10th edition of "Standard Methods" (1), a great deal of work has been done on the membrane filter method, and particularly on culture media, since the 10th edition was published.

Work by Fifield and Schaufus (13) has shown that the M-Endo-MF medium used without enrichment, produces a very low proportion of false positives. The work reported here shows excellent agreement with total counts on pure cultures, indicating a low proportion of false negatives.

Analysis of the results obtained in surf-water testing in the Orange Co. laboratory shows a very high percentage (92 to 94 per cent) of confirmation with brilliant green bile. To investigate the possibility that the basic cause for the lack of agreement between the MPN and the MFC might be the production of false positives in the confirmed test, a short series of tests was made. Positive lactose tubes, obtained from routine samples of surf water, were transplanted to EMB as well as BGB; and cultures from the EMB plates, where growth occurred, further transplanted to lactose broth and agar slants, thus running the completed test in parallel with the confirmed test. While the number of tests made is not large enough to permit a final conclusion to be drawn, the data shown in Table VIII point to a high incidence of false positives.

TABLE VIII.—Determination of False Positive Fermentation Tube Results

Item	No.	Per cent*
Positive lactose tubes	173	—
Positive BGB tubes	160	92.5
Positive EMB cultures	137	79.2
Positive completed tests	87	50.2

* Per cent of positive lactose tubes.

This limited study would indicate that MPN results based on the confirmed test using BGB are high because of gas production in this medium by non-coliform organisms, and that the actual MPN, based on the completed test, might be less than 60 per cent of the MPN based on the confirmed test. It is anticipated that this study will be continued by running the confirmed and completed tests on a large number of samples.

This limited study also indicates that EMB is more effective than BGB in eliminating false positives. However, it has yet to be determined whether the efficiency of EMB outweighs the convenience of BGB.

One other incidental conclusion from this study is of interest. All of the cultures which failed to complete after transplantation from EMB did so by failing to produce gas in lactose. Spore-forming organisms were not found in any culture.

Limitations of the Membrane Filter Method

While the membrane filter method is a relatively simple procedure, it is not as simple as many have claimed, and there are certain points in technique which must be adhered to rather rigidly.

Like all differential media dependent on dyes for their action, concentration of dye in the M-Endo-MF broth is critical, as well as concentration of the other ingredients. Care must be taken that the medium is properly made up. It has been found that solution of the dry material is facilitated by wetting the dry medium with alcohol first, then adding the water.

Sufficient medium must be added to the pad to provide optimum moisture, but excessive amounts should be avoided, lest spreading growths be produced. Excessive humidity in the incubator can also cause spreading.

Proper illumination of the filters during counting is very important. With proper illumination there should be no difficulty in differentiating sheen and non-sheen colonies.

The total number of colonies, both coliform and non-coliform, should not exceed 100 per 47-mm filter. Crowding of colonies will produce interference and low results.

Selection of the proper volume for filtration is not easy if the expected range of count is not known with fair certainty (a similar problem is encountered in the fermentation tube method in selecting an appropriate dilution). The solution is to filter more than one size portion.

In the case of sea water from areas where the coliform concentration is very low, the attempt to use large volumes of sample may result in the production of a dense growth of non-coliform colonies, so that the very small number of coliform colonies may be obscured.

Turbidity of the sample, under certain conditions, can present a problem (14), although in most cases with sewage or sewage-sea water mixtures the amount of dilution necessary will reduce the suspended matter concentration to a point where it will not interfere.

Summary

The work on which this report is based is limited to the estimation of coliform concentrations in sea water or sewage-sea water mixtures. This work comprised the following experimental studies:

1. The examination of two groups of samples of surf water, totaling 695 samples, by the membrane filter method in parallel with the fermentation tube test.

2. A series of 28 experiments where replicate MPN and MFC determinations were made on settled, strained, diluted sewage.

3. A series of eight experiments where similar replicate MPN and MFC determinations, along with replicate total counts, were made on diluted broth cultures of coliform organisms.

4. A short series of tests to determine the proportion of false-positive BGB tubes obtained from sea-water samples.

Conclusions

It is realized that further work in this and other laboratories will be necessary before final conclusions can be made on certain points. However, a study of the data reported herein leads to the following inferences:

1. The membrane filter method of estimating coliform densities in sea water and sewage-sea water mixtures has advantages over the fermentation tube method by virtue of the labor, time, and materials saving.

2. The results of the membrane filter test are available earlier, and consequently, of more value in a control program.

3. The precision of the membrane filter count is superior to that of the most probable number derived from fermentation tube results.

4. The fact that the membrane filter count is generally lower than the most probable number has not been shown to be caused by poorer accuracy of the filter method. The data suggest that if preliminary evidence can be substantiated the apparent inaccuracy of the fermentation tube method may be caused by the production of gas in brilliant green bile by non-coliform organisms.

5. In a limited number of replicate tests on samples containing only coliform organisms, the membrane filter count was in better agreement with the total count than was the most probable number.

6. Like any other procedure, the membrane filter method has limitations, and must be applied properly.

Acknowledgments

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THE OPERATOR'S CORNER

INTERPRETATION OF SEWAGE TREATMENT PLANT TESTS—PANEL DISCUSSION

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The comments that follow were taken from a transcript of a panel discussion held at the 8th Annual Joint Meeting, Florida Section, American Water Works Assn. and Florida Sewage and Industrial Wastes Assn.; Jacksonville, Fla.; Nov. 10–13, 1957. Panel members included Theodore Jaffe, Professor of Civil Engineering, Alabama Polytechnic Institute, Auburn, Ala., and A. M. Buswell, Research Professor of Chemistry and Sanitary Science, University of Florida, Gainesville, Fla.

Dr. Sawyer: I believe a good way to break this topic down is to think of the analyses that apply to sewage and industrial wastes as one category. The other category would be for those analyses which apply to sludge and sludge disposal. Here are a few things under sewage and industrial wastes or polluted waters, if you prefer, that we might consider. The matter of pH—are you sure that you know how to interpret pH? Are you sure that you know how to interpret settleable solids and how far you can go in an interpretation of settleable solids? How about suspended solids? Are you sure that you know how to interpret that test and know its limitations? How about total solids tests? How many of you are still running total solids? To get something started I want to say you are wasting your time.

John W. Wakefield, Director, Department of Water Resources, State of Florida, Jacksonville, Fla.: Why do you think we are wasting our time?

Dr. Sawyer: First, may I say I am talking about sewage, not industrial wastes or sludge. The total solids test measures solids on evaporation or total residue and that, of course, measures not only the organic matter which is in the sewage, but it measures everything else present in the form of mineral solids. Total solids here in Florida might run 800 or 900 ppm, while in New England we would probably find 250 or 300 ppm total solids. It is very difficult to interpret unless the total solids in the carriage water is stipulated. Does anyone have a different idea?

Emil Jensen, Director, Division of Engineering and Sanitation, State Department of Public Health, Seattle, Wash.: How about the use of pH for detecting infiltration in sewers?

Professor Jaffe: I think a much better index of infiltration in Florida would be the chloride content, particularly around the coastal areas. I think, too, that the chloride test is one

that the average plant operator in Florida is not sufficiently familiar with. I'd like to make a plug for some of your short courses spending a little time on chloride determinations.

Professor Buswell: I was just wondering whether the question wasn't directed toward the presumption that the infiltration would be shallow ground water after not very much percolation, therefore being fairly highly saturated with CO_2. In hard water districts I would expect that the pH might go down as infiltration increases or especially if storm water gets into the sewer. On the other hand, it might go up. I have always regarded both water and sewage analyses as important primarily from the standpoint of comparison. I'm not too much in favor of general standards. If you know what normal readings are and then correlate them with known changes, over a period of time you build up a back-log of information from which to draw conclusions.

Dr. Sawyer: I am inclined to agree with Professor Jaffe that we have better indicators to detect infiltration. Chloride tests as he has mentioned, and change in alkalinities sometimes can be used. Fundamentally, the pH determination is not too satisfactory for this reason: sewage ordinarily is quite well buffered so that when even fair amounts of water, whose pH may be a little bit above or below it, are added, the whole mixture will approach the pH of the sewage itself.

Ralph Baker, Sanitary Engineer, Florida State Board of Health: I'd like to take exception to the use of chlorides as an indicator of infiltration. I feel that sewers in Florida are tide level, relatively speaking. They are near the surface of the ground and we don't get much salt water in them.

Professor Jaffe: Well, if you are going to count on only rain water coming down and infiltrating, that may be true. But there are plenty of other conditions where rain water is going to seep down into the ground and then come back up at some other level with an increased chloride content. In regard to pH versus chlorides, I think chlorides are a lot simpler to detect. Also, simpler equipment is required. Besides, many other things might change the pH.

Dr. Sawyer: I think we could pursue this matter for some time. Let's, however, bring up some of these other matters.

From the floor: Are there any plants that are using oxidation-reduction potentials in the routine control of their plants?

Professor Jaffe: I don't really know of any plants that are actually using it but I know of several instances where it has been suggested. Several of the New York City plants have tried it. There have been any number of articles in the literature. Some of the difficulties with it are the equipment and interpretation of results. Frankly, in the lab it is very difficult to keep the electrodes clean.

Professor Buswell: Dr. Gruen, in a recent paper, emphasizes that the manipulative and laboratory procedures are quite difficult. For example, pH was first announced in 1908. (Imagine having lived before pH was known! It was a mess!) However, it wasn't until the mid-20's that we had a good rugged hydrogen electrode and that was necessary before we could have the colorimetric method. Now the amount of work that's been done on oxidation-reduction potential, which was practically simultaneously discovered, has been much more limited and as Professor Gruen points out, it is not a routine plant procedure at the present time. It is still a research tool and not too easy a research tool to use.

Dr. Sawyer: I would just like to add one comment. Fundamentally, the ORP is a measuring stick that can be used to measure the intensity of anaerobic conditions. For example, consider the dissolved oxygen test—you

might run a DO and find no dissolved oxygen. That is worth knowing, but it doesn't tell how bad off you really are. The ORP measurements allow you to go way down on the scale and measure degrees of oxygen deficiency indicating: when all nitrates are exhausted; when all sulfates are exhausted; and so forth. It has real value there.

I don't mean to say that ORP is limited to these very things but I think it will find its greatest application in sensing anaerobic conditions and how bad they are. It possibly can be used also for sensing the degree of aerobic conditions but my experience with it under aerobic conditions is that after the DO gets above 1 ppm it doesn't tell you very much. Most of you know that if you maintain more than 1 ppm of DO in an aeration tank you are, of course, running into pretty expensive operation, but if you are doing it by ordinary control methods you'll find that the manpower necessary to maintain around 1 ppm is more expensive than the cost of compressing the air. What we need is instrumentation to get to the degree of refinement or efficiency that we are looking for. If an ORP cell will do it, I predict that it will have a tremendous market in the field of sewage treatment as far as activated sludge plants are concerned. There is a new cell * on the market that looks as though it could be used in plant control.

E. C. Shreves, Jr., Ocala Sewage Treatment Plant, Ocala, Fla.: Supposing your laboratory personnel were available two hours per day for running tests on a complete sewage treatment plant. What tests would you recommend?

Dr. Sawyer: That is a very good question and I'd like to have the panel see what they would propose as tests. This is a complete treatment plant involving separate sludge digestion.

* Manufactured by Fischer and Porter Company.

Professor Jaffe: From the standpoint of protection of your city against the criticism of polluting the streams I would say unquestionably, BOD. But, of course, that's reducing it to a pretty low value, but then you've set a pretty low limit.

Professor Buswell: Well, first thing I would say—"What does the State Health Department want?" Suppose you've got an activated sludge plant—I think it is pretty important that you watch that DO in your aeration tank from the cost angle.

Dr. Sawyer: There is one thing I'd like to throw in here. I've heard some of the "old timers" say, "Give me a few BOD bottles and some good old Imhoff cones and I'll run this treatment plant for you." I think too often the Imhoff cone is overlooked. The Imhoff cone test will tell you nearly everything your primary treatment plant is doing. Also, with the Imhoff cone test results you have a record of the material, that is, the settleable material, that will go into the river and it is just as good as the suspended solids in the final effluent in the final analysis. Those two tests, Imhoff cone and BOD, are what I would concentrate on.

Let's shift our attention now to sludge digestion and the analysis of sludge. Who runs volatile acids in this group? Do you have any trouble in running the test or interpreting the results?

Professor Buswell: In anticipation of this question I wrote down a few comments which I'll read, if you don't mind. For the benefit of inexperienced analysts, the following suggestions are made to supplement the directions in "Standard Methods": (a) The overflow liquor to be tested should be free from visible particles of sludge. Settling is usually satisfactory but filtration through coarse filter paper or centrifuging may be necessary. (b) Glass beads or pumice should be added to prevent bumping. (c) A 500 ml flask should be used for the distillation (too

small a flask will result in "carry over" of H_2SO_4). (d) The rate of distillation is important. Too rapid a rate will result in a "carry over" of H_2SO_4. (e) If carry over is suspected, the distillate may be tested for sulfates with $BaCl_2$, or if the sample is excessively high in chlorides a test with $AgNO_3$ is advised. (f) Accuracy. Since variations of less than 200 to 300 ppm are not important from the standpoint of operation, a high degree of accuracy is not necessary. A good reproducibility is desirable since the application of the test is empirical.

The steam distillation method has value especially in research studies. Data are not available at present upon which its use as a control test can be based.

Chromatographic methods, now under active study, are being rapidly improved and simplified. I believe that within a few years automatic equipment will be available to continuously analyze both the overflow liquor and the gas.

Now, as to interpretation, I feel that the limit of 2,000 ppm has been overemphasized. A sudden, that is, a 24-hr increase of 200 to 300 ppm is a danger sign, whether it occurs at a low or high level. For example, an increase from 900 to 1,200 ppm in the volatile acids in 24 hr indicates the need of increased circulation and perhaps a decrease in the feed, but an increase from 1,900 to 2,000 in a tank which had been operating smoothly for some time would not be considered too serious a matter. Furthermore, this figure of 2,000 ppm was taken from a rather flat curve. In our own experience in the laboratory and elsewhere there are plenty of examples of tanks that have come up to 2,200, 2,500, and even 3,000 ppm without trouble. However, we found that at 2,000 ppm we were likely to get a "stuck tank" which is a rather serious matter.

Professor Jaffe: I just wanted to point out that in this group I think there were three person who ran the volatile acids test. There are probably two reasons why it is not more frequently used; first, the techniques and the apparatus, and probably more important—most of you have not had clearly explained just why and how you can use the test. One of the main reasons for running the volatile acids test is to determine more quickly just what condition the digester is in. You can measure gas production (and this is a good indication); you can measure pH; you can measure alkalinity; they are all good but they are late indicators. Gas production starts to drop after you've gotten into trouble. Volatile acids on the other hand will start to change before gas production drops. If you can detect trouble at the beginning then you can do a lot more about it.

Dr. Sawyer: I certainly agree with all that has been said. Anyone who is attempting to operate a digester with reasonably high loadings is almost at a complete loss to keep things in balance without this test. There have been other tests proposed such as pH and many digesters have been operated with just pH determinations. The main trouble with the pH determinations in the first place is that you must have something that tells you what the pH is. Colorimetric procedures, of course, are out of the question, and if you use electrometric methods a lot depends on what you've done to the sample before you get around to measuring the pH. For instance, I was in one laboratory where they filtered the sample and then measured the pH. I said, "Why are you doing this? You are losing carbon dioxide while you are filtering it." Actually they were, because when a new sample of sludge was brought in it had a pH of 6.7 and when they finally got through filtering it the pH was up to 7.2. They had been running pH that way for some time and they thought everything was all right

because the pH was 7.2. Actually they were on the border of trouble.

I would like to add that the volatile acids and alkalinity of a digester are interrelated. If you are dealing with a digester wherein the alkalinity is relatively low, you have low buffering capacity, and the volatile acids that the digester can accommodate without distress are relatively low. Most digesters (conventional type) will operate with the volatile acids in the order of 150 to 200 ppm. But if the volatile acids get as high as 500 ppm in conventional digesters you had better be doing something about it. And that is where, of course, the volatile acids test is so valuable in that it points out the onset of trouble. The alkalinity in a digester is dependent on two major factors: (a) the alkalinity in the domestic water, and (b) the concentration of sludge fed to the digester. If you feed a 2 per cent sludge to a digester the alkalinity will usually poise around 1,500 to 1,800 ppm. If you are feeding a sludge with 6 to 8 per cent solids the alkalinity will run up around 4,000 to 5,000 ppm. In the latter case you have tremendous buffering capacity and the digester can stand a considerable variation in volatile acids content without any distress simply because it does not knock the pH down. The thing that bothers the methane organisms is really a reduction in pH, in most cases.

From the floor: Is pH a reliable test?

Professor Buswell: No, we have examples where it isn't reliable. We have no examples where a low volatile acids content is not a safe operating condition. Another digestion indicator is the CO_2 content, which increases as you move toward a sour tank. But by the time the CO_2 content has gone up much you are already in trouble. In operating a digester I like to know not only the volatile acids, but the alkalinity, the amount of gas per day per pound of organic matter added, and the composition of the gas. Now those tests put quite a load on the analytical laboratory. Probably the most reliable indicator, if you keep your tank circulating and allow no accumulation of gas, is the gas yield. If a certain number of pounds of organic matter has been converted into so many cubic feet of gas then you know your digester has done that much work within that period of time. However, the accuracy of collecting and measuring the gas evolution is frequently not quite reliable.

From the floor: How often are volatile acids run and how are the results interpreted?

Professor Buswell: We run volatile acids daily and if the volatile acids jump as much as 200 to 300 ppm from any starting point we begin to watch a little more carefully and we are particularly careful about circulation. Then if, on the second day, there is another jump of 200 to 300 ppm the feed must be interrupted immediately. I'd say that during this 24- or 48-hr period the remedy must be applied. Otherwise you may get a "stuck tank." Now you don't always have trouble. Ordinary treatment plants are designed with such a large digester volume that many digesters go into operation without any volatile acids or alkalinity determinations or anything else, and they get by all right. Operators hear about that and think they should not have to go to the trouble of running volatile acids, but once somebody gets a "stuck tank" they wish they had done the volatile acids test. As the loads get higher and higher it becomes more and more necessary to follow the volatile acids changes in the starting of a digester.

Dr. Sawyer: I would like to add that these control tests are going to become much more important in the future than they have been in the past. As Dr. Buswell has indicated, so many of the old tanks are so far over-designed that anybody who can start them up shouldn't have any problem at all. But in the future that picture is going

to be changed because of the matter of capital investment savings. With high-rate digestion, for example, once the digester is started it will have to have close control to keep it going.

I think what we really need now is for some of you men who are sitting out there this afternoon to get up and tell us how you operate your plant and how you keep your digester running and what you do. You're the men who work with them and when something happens you have to handle it and when you handle it you forget all about it. You seldom talk about it in the "journals." We need the information from you, especially on the practical angles.

From the floor: What routine tests would the panel recommend if the volatile acids test cannot be run?

Professor Jaffe: I think Dr. Buswell pointed out that at least pH and alkalinity ought to be run. With just a little bit more money and time you can run suspended and volatile solids. If you run a solids balance at least you know what you are putting in and what kind of sludge you are getting out of the tank. I do think these three simple tests—pH, alkalinity, and solids—ought to be run.

LOW-COST LAB AND SIMPLE RECORDS

By Gerson Chanin

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At the larger sewage treatment plants there should be a well-equipped laboratory under the direction of a capable chemist. At the smaller plants where this is not possible, the operator can become adept in performing certain very important, yet comparatively simple, routine laboratory operations.

The San Francisco Bay Section of the California Sewage and Industrial Wastes Association has devoted a good part of its operators' training sessions to stimulating and persuading the plant operator to do more testing and record keeping. Despite these efforts little progress has been made toward this goal.

Excuses

Many reasons are given for not performing tests, including:

1. The high cost of setting up a laboratory.
2. Fear that the tests are too technical and require a "college man."
3. The feeling that, after all is said and done, laboratory tests do not help much in plant operation.
4. The feeling that the only value of laboratory testing is to gather information "for the record."
5. The lack of time to do such testing.

Of these excuses, only the lack of time may, in some cases, be valid.

Let us examine these excuses further.

Cost

While it is true that a complete sewage treatment plant laboratory costs a great deal of money, there are many tests which require only a minimum investment.

1. Settleable solids. This test involves only the purchase of some Imhoff cones, at about $6.00 each, and a rack to support them, at about $8.00. With a couple of wire coat hangers and a block of wood, the ingenious operator can readily make an Imhoff cone support.

2. Sludge solids. This test should be an integral part of the routine at all plants having digesters. This, too,

is a test which can be set up at a minimum investment. A pan balance of 0.1 gram sensitivity can be purchased new for from $15 to $100. A wise buyer can pick up a good second-hand balance for much less. The solids can be heated in disposable aluminum pans, available at a few cents each. To drive off the water, an ordinary infrared heat lamp may be used as a source of heat. The whole set-up shouldn't be more than $25. The volatile solids test may be done by using a gas operated Bunsen burner as a heat source. A Bunsen burner costs only a few dollars.

3. Dissolved oxygen and BOD. Though these tests are complicated from the chemist's viewpoint, they may still be performed by all plant operators at relatively low cost. Purchase of prepared solutions for the dissolved oxygen test and the necessary glassware will cost only about $35. To the operator whose effluent or receiving waters must meet a minimum DO or a maximum BOD requirement, such tests are invaluable. To the operator of a secondary treatment plant, the assurance of aerobic conditions throughout the process is extremely gratifying.

As for a BOD incubator, most any type of container and a cheap aquarium thermostat and heater will serve fairly well. Some old refrigerators have a bellows-type thermostat. A simple screw adjustment will convert this type to a 20°C incubator in a few minutes.

4. Bacteriological tests. The membrane filter bacteriological techniques have brought bacteriology within the reach of the plant operator. For an investment of less than $20, it is possible to set up and perform the coliform test. The cost of an incubator (the major item) can be avoided by incubating the samples on the person. The breast pocket of a jacket or shirt makes a pretty good incubator.

5. With a little common sense and good judgment, other tests can be adapted to a low-cost laboratory.

Technical Difficulties

While it is true that chemistry, biology, and bacteriology are complex sciences, an operator does not need to be a chemist or bacteriologist to run control tests. Remember, for example, that one doesn't have to be an automotive engineer to be able to drive a car. So, too, it is possible to perform a laboratory test without completely understanding what goes on in the test. However, even such technical know-how is available to the treatment plant operator from many sources, such as operators' schools, textbooks, meetings, health departments, etc. The operator should take advantage of all of these sources of information.

Value of Tests

Some operators have the idea that the results of laboratory tests are merely "for the record" and have little or no direct application to plant operation. Nothing could be further from the truth. They say, for example, "Why run solids tests on raw sludge? By the time the test is finished, you've already put the sludge in the tank." While this, of course, is true, it shows only a very limited understanding of the over-all digestion process. How can the operator ever know what he is putting in his tank unless he performs such tests? How can he ever know whether he is operating his digesters efficiently unless he performs such tests? By performing many of these solids tests, the operator soon becomes pretty good at judging the solids content of the sludge from its appearance.

The operator should look at sewage treatment as a long range operation. If he finds that operation last week was not up to par, he should attempt to do something about it.

Because some tests take several hours or several days to complete is not

justification for performing no tests at all. Many tests will give usable results in a short time. In one hour the efficiency of sedimentation can be determined by performing the settleable solids test. The need for additional prechlorination can be determined in 15 min by performing the test for dissolved sulfide. The need for increasing the air in an aeration basin can be determined in just a few minutes.

Testing for the Record

As for something "being for the record" there's nothing wrong in that either, providing the records are used for their intended purpose, which is to supply the operator with the information he needs to operate his plant efficiently. Often the operator gets the notion that record keeping is done to keep his boss happy or to supply data to the health department or the water pollution control authority. While all these are true, they should be secondary to its main value—supplying operational data.

Record Keeping

At a great many plants, even record keeping is virtually nonexistent. This results from the mistaken feeling that record keeping is difficult. In practice, the operator should keep only those records he can and does use, and these may be quite simple. The operator who is not now keeping records may find it advantageous to start slowly. Additional information can be recorded as the need is realized. For example, he may begin by merely keeping a record of incoming sewage flow. Because it is well known that both sewage flow and load are very low during the late evening and early morning, smaller sewage plants are often left unattended at those times and sludge is not drawn. But, are low night-time flows always the case? By recording flow data and analyzing them, this question is easily answered.

A combination of flow data and the number of hours of pumping will permit the determination of pump capacity. It will also indicate when the pump capacity begins to fall off and when maintenance may be necessary. A regular maintenance program based on hours of pumping could be set up. A record of sludge-gas meter readings will give an idea of how digestion is going. Any unexplainable, big change in gas production indicates trouble. An examination of a year's gas metering data will tell when to expect sufficient gas to operate a gas engine and when auxiliary fuel may need to be purchased.

The mere notation of the number of cubic feet of grit and screenings handled will indicate many things, including: some characteristics of the sewage; the effectiveness of the degritting and screening facilities; and, to a degree, the extent of the sand problem.

At one treatment plant the only record kept was the time and date the plant went into operation. A councilman called the operator and wanted to know what he was doing to make a brand-new sewage treatment plant smell so bad. The operator asked what the specific complaint was. "Last Tuesday, I got a phone call from a citizen living near the plant about the odor from the plant," said the councilman. The operator had the most complete squelch ever heard. He said, "Why, we didn't begin operating until 12:30 PM last Thursday."

Even the simplest records will be of help in plant operation and the planning of future expansions. A study of these records will hasten the day when the operator finally becomes the master of his treatment plant.

FIRST-YEAR EXPERIENCES AT SAN JOSE, CALIFORNIA *

By Frank M. Belick

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The San Jose sewage treatment plant is located at the most southerly end of South San Francisco Bay and serves an area of 60,000 acres. Within this area are located seven incorporated cities, four sanitary districts, and three county sanitation districts.

Initial treatment plant studies and design were completed in 1951. Revisions of plans and specifications were made in 1954. A study is now being conducted which will lead ultimately to a secondary treatment plant for San Jose.

Plant Facilities

The primary treatment plant consists of prechlorination facilities, including two 6,000-lb chlorinators and covered storage for 40 tons of liquid chlorine; four vertical bar screens, a screenings conveyor, and grinders for removal of coarse floating material; four 85 ft-long grit channels and collection equipment; six 34- by 70-ft preaeration tanks and six 34- by 150-ft sedimentation tanks; three 100-ft diameter digesters with floating covers; fifteen acres of sludge lagoons; a gas utilization system; a 70-mgd pumping system; and a 480-v electrical distribution system including three dual-fuel engine-generator sets.

A staff of 19 employees operates and maintains the plant structures and equipment necessary to process the waste from the estimated 264,000 persons contributing to the sewage collection system. In addition, there are a number of diversified industries including 24 fruit and vegetable canneries, which contribute an additional average flow of 15 mgd during the months of August, September, and October.

Plant Start-up

Preparation by City

Preparation for the operation began with the selection of plant personnel. This required job descriptions for the positions of operator, assistant operator, plant maintenance mechanic, plant maintenance electrician, and chemist. A staff of 9 employees was available for operation on start-up day. The full complement of 19 employees was available by the end of the 30-day test period. Only three employees had previous sewage treatment experience.

In cooperation with a major oil company a detailed lubrication survey was made. Copies of the data were given to the contractor together with an adequate supply of oil and grease of the City's preference in order to avoid changing brands at a later date. Initiation of a detailed preventive maintenance program was delayed until the test period was over.

Operational Problems

Digester operation began with the hiring of a private septic tank service to haul 100,000 gal of sludge seed from the nearby Palo Alto treatment plant at a cost of $16.50 per 1,000 gal. The sludge seed was added to Digester No. 1 by initially discharging the material through a ground level manhole and later by means of a special waste tank and pumping system provided in the design to handle septic tank wastes. Fresh sewage was simultaneously introduced into the tank in sufficient amount to raise the cover off the

* Presented at the meeting of the Santa Clara Valley Section of the California Sewage and Industrial Wastes Assn.; Alviso, Calif.; Feb. 27, 1958.

corbels. Because of previous difficulties in preventing back-flow through the 37 pressure relief valves located in the digester floor slab, sacks of semi-dry sludge were placed over each relief valve to keep the cover in tight contact with the valve until the thick digested sludge filled the lower area. Circulation of bottom sludge and the addition of steam was immediately started to expedite production of usable sludge gas.

In anticipation of receiving tons of stored-up grit during the first day of operation, all four grit channels were placed in operation. However, the first grit appeared 12 hr later and in normal quantities. Shear pin breakage on both bar screens and grit collectors was excessive for several weeks. One shift replaced 48 pins during a single 8-hr period. Hours of checking shaft alignment, rail position, and chain lengths finally resulted in reasonably smooth operation.

Some of the most revealing and educational events occurred during the first month of operation, while still under the contractor's supervision. During the first week the following incidents occurred: (a) A 100-hp blower motor burned up, requiring complete rewinding. (b) A jacket water pump tripped a normally closed circuit on the engine control panel causing the engine generator sets to stop. This in turn stopped the blowers, causing the aeration lines to fill with sewage and in turn flood the air-lift booster compressors. (c) On another occasion a grit chamber drain line inadvertently left open during the day shift allowed sewage to flood the sludge concentration room to a depth of 16 in. The sump pump motors in this room were damaged along with two sludge pump motors and the electrical control panel. (d) Again, while attempting to operate the sludge concentration equipment, the rotary compressor received a back-flow of sludge resulting in severe damage to this unit.

Such incidents as these led to suspension of operation until all automatic controls, alarms, and other safeguards were in working operation. Upon resuming operations and also profiting from the previous week's experience, operational difficulties were minimized.

It was noted that 10 days after operation commenced, sludge gas with a carbon dioxide content of 66 per cent, raised the low pressure gas holder for the first time. The gas would not burn in the waste gas burners but did serve the purpose of purging the gas utilization system of trapped air.

Difficulty was encountered in placing the remaining two digesters in service because of lack of sufficient steam for sludge heating. The steam salvaged from the dual-fuel engine jacket water cooling system was inadequate to heat more than one digester. Provision was made in the design for two 75-kw immersion heaters as boosters for the steam supply. When installed, these units were found to be improperly wired and had to be returned to the manufacturer for rebuilding. Such delays resulted in operation of the digesters at temperatures from 70 to 75°F for four months instead of the more effective 95 to 100°F range.

Operating at this lower range also delayed by four months the recovery of suitable digester gas for the dual-fuel engines resulting in the use of an additional 26,000 gal of diesel fuel.

At this point it should be brought out that the injection of live steam into the sludge can be damaging to the bitumastic coating on the underside of the roof if the sludge flow is cut off. This situation was corrected by the addition of a thermostat in the digester dome. Through this arrangement the steam valve is closed whenever the temperature inside the dome exceeds 160°F.

Even though a number of unusual operating difficulties were encountered during the first year most of the plant equipment performed adequately.

Some of the bright spots were the smooth performance of the engine-generator sets and power distribution system, the aeration system, gas utilization system, and the sedimentation tank equipment. The excellent arrangement of the equipment, piping, controls, and the building layout is appreciated by the operators.

Effects of Cannery Wastes

Waste Volume

By mid-year plant operation had smoothed out appreciably and plant personnel developed a sense of false security, which quickly disappeared during the first week of August when the initial wave of cannery waste proceeded to unbalance the carefully developed routine.

Overnight, average week-day flows increased from 20 to 37 mgd, and occasionally even higher. Peak flows jumped from 30 mgd to rates in excess of 52 mgd; the latter flow represented the ultimate capacity of the intercepting sewer leading to the plant. An occasional surcharge on the venerable 7.5-mile long 60-in. brick intercepting sewer resulted in numerous breaks. Relief for this line could only be provided by the construction of a reservoir midway between the populated area and the plant. The reservoir filled during peak flows and drained at night. A parallel 60-in. intercepting sewer to alleviate the excess flow is in the planning stage.

Waste Characteristics

During the peak fruit-processing season, average daily BOD values increased from the 400- to 500-ppm range of the non-canning season to 1,000 ppm and greater. Suspended solids values increased by a lesser degree, from average values of 450 to 500 ppm to approximately 750 ppm. This occurred over a 20-hr period each day, 6 days per week, during the months of August, September, and October. A summary of operating data for 1957 is shown in Table I.

The tendency of mixtures of domestic sewage and cannery waste to form excessive scum layers on the surface of sedimentation tanks was illustrated dramatically at the San Jose plant. The particles of fruit, buoyed by carbon dioxide resulting from acid fermentation of the mixture, rise and cover the surface of the tank to depths of from 4 to 6 in.

Maximum available aeration at the rate of 0.15 cu ft per gallon of sewage with 1.1 hr detention reduced this problem but did not eliminate it. It was found expedient to keep a man on the tanks to continuously remove the scum by rake as it formed. An inopportune water shortage at the height of the canning season allowed for only intermittent use of the scum sprays. The plant water supply is developed from a 550-ft well which began pumping sand a few weeks ahead of the canning season. Delays in correcting this situation necessitated hauling water from a nearby farm. A cyclone separator has since been added to keep sand out of the storage reservoir. However, while hauling water to the storage tank an appalling situation was discovered—the tank was losing water faster than it could be hauled in!

A careful check of the distribution system uncovered a leak of the magnitude of 100 gpm between the tank and the No. 2 water system pumps. After determining that the leak was at a depth of 18 ft in a sand-filled, somewhat inaccessible area, the 8-in. cast iron water line was abandoned and later replaced by a new 70-ft section, utilizing plant personnel.

Digestion

During the winter and spring two digesters are used for primary digestion and one for secondary digestion. With the advent of the canning season, all three tanks are operated as

TABLE I.—Summary of Operating Data for 1957

Month	Avg Flow (mgd)	Influent				Effluent				Removals			Raw Sludge			Sludge Gas	
		Susp. Solids (ppm)	Settl. Solids (ml/l)	5-Day BOD (ppm)	pH	Susp. Solids (ppm)	Settl. Solids (ml/l)	5-Day BOD (ppm)	pH	Susp. Solids (%)	Settl. Solids (%)	5-Day BOD (%)	Vol. (1,000 gpd)	Solids (%)	Volatile Solids (%)	Produced (1,000 cu ft)	Fuel Value (Btu/cu ft)
Jan.	20.9	485	9.3	494	6.8	146	0.3	297	6.6	70	97	40	184	5.7	71	74	—
Feb.	22.1	451	9.7	552	6.8	114	0.2	307	6.7	75	98	44	142	—	—	74	298
Mar.	21.0	502	9.1	407	7.0	236	2.7	289	7.2	53	70	29	96	—	—	96	510
Apr.	20.0	430	7.3	364	7.0	148	1.4	223	7.1	66	81	39	136	7.3	—	192	552
May	16.1	483	8.2	311	7.2	92	0.9	169	7.1	81	89	46	169	7.2	71	329	492
June	17.0	427	16.2	328	7.1	115	0.4	185	7.0	73	98	44	199	5.9	73	396	561
July	20.5	533	19.9	518	7.0	104	1.1	327	6.8	81	95	37	174	5.0	—	340	518
Aug.	31.7	564	34.0	896	6.2	261	11.9	694	5.6	54	65	23	246	5.1	80	342	453
Sept.	31.9	432	24.6	731	6.7	171	5.5	507	6.1	60	78	31	262	3.9	72	—	445
Oct.	22.9	472	17.2	460	7.1	100	0.4	296	7.0	79	98	36	249	5.1	73	—	489
Nov.	15.3	1,018	29.9	471	7.3	126	0.9	252	7.1	88	97	47	260	5.1	66	—	515
Dec.	15.2	1,454	32.9	580	7.2	142	1.0	279	7.1	90	97	52	235	5.8	71	—	498
Avg	21.2	604	18.2	509	7.0	146	2.2	319	6.8	76	88	37	197	—	—	341	444

primary digesters and sludge lagoons are used for final digestion. Continuous circulation of bottom sludge was practiced and gas production was excellent. Foaming was a rare event throughout the entire season. This condition was maintained despite the fact that large volumes of 3- to 4-per cent sludge were withdrawn almost continuously from the sedimentation tanks. No sludge thickening was practiced because the sludge concentration system was temporarily inoperative. The sludge was withdrawn from the tanks and pumped to the digesters at a nearly constant rate of 175 gpm. This rate provided a detention time of 20 days and required the withdrawal of 1.5 ft of sludge from each digester per day. The sludge solids amounted to some 100,000 lb per day.

During the height of the canning season and at a time when operating problems were in abundance, two 8-in. cast iron sludge lines ruptured at a most inconvenient depth of 20 ft below the pavement surface. A good guess was made in regard to the location of the break and excavation by a clam shell exposed two shattered 45-degree bends. These were replaced and the plant was restored to full operation within three days.

Need for Additional Treatment

Unfortunately, bypassing the sewage flow for the three-day period in August apparently left sufficient evidence in the form of fruit solids on the surface of the discharge waters to impel the manager of a nearby community to wire the governor and demand immediate relief from what was erroneously considered to be complete plant failure of a permanent nature. This was followed by a survey conducted by the Regional Water Pollution Control Board in September, to determine the degree and source of pollution in the South San Francisco Bay receiving waters. Included in the board's report was a recommendation that secondary treatment for San Jose be expedited in order that the prescribed requirements be met.

Future Improvements

Certain improvements to aid primary plant efficiencies will be made at an estimated cost of $30,000. These improvements will include: sludge gas recirculation for one digester, sedimentation-tank baffle revisions, an increased compressed air supply, and a chlorinated-effluent line to the inlet of the sedimentation tanks.

Long-range planning under way consists of a study of all applicable methods of secondary treatment with emphasis on both capital and operating costs in order to determine the type of treatment best suited for the San Jose area. A pilot plant, soon to be placed in operation, will aid in making this determination. In addition to assessing the relative merits of the trickling filter and activated sludge processes other methods of treatment such as anaerobic activated sludge will receive consideration. The latter method shows promise in handling strong wastes with a significant saving in both first cost and operating costs. Construction of the secondary treatment plant is scheduled for Sept. 1960, and operation of some of the plant units should be ready by the 1962 canning season.

RAW SLUDGE PUMPING SYSTEMS*

By Elmer E. Ross

Superintendent, Sewage Treatment Plant, East Bay Municipal Utility District, Oakland, Calif.

A large part of the total operating and maintenance effort at the larger sewage treatment plants is devoted to the removal, processing, and disposal of the solids removed as sludge. Consequently, the sludge-handling system should receive careful consideration during the design stage if efficient and economical operation is to be achieved. As much flexibility as possible should be built into the pumping system because of the variable characteristics of sewage sludges. Proper consideration must also be given to the severity of service when selecting and specifying equipment.

Despite the care taken in the original design and selection of equipment, modifications and additions, as well as adjustments in operating procedures, may be necessary if maximum economy is to be realized. Such has been the experience at the East Bay works.

System Design

General Plan

At the time the East Bay plant was designed, it was the practice at most small plants and at many of the larger plants to remove the settled sludge from the individual sedimentation tanks by means of air lifts or telescopic valves and pump it to one or more large storage tanks or vaults, whence it was repumped to the digesters, after being allowed to concentrate. Skimmings and floating sludge were also generally discharged to these tanks. Disadvantages of this general method include the release of odors and a large labor demand. However, advocates claimed that the solids content of the sludge fed to the digester could be kept uniformly high.

After considerable study it was concluded that equally good results could be achieved with a smaller capital investment and less operating labor by pumping the settled solids directly from the sumps in the sedimentation tanks to the digesters. The storage and concentration tanks were omitted and each of the ten sedimentation tanks was provided with a sludge pump arranged to discharge directly to the digesters through a single force main. Each pump was equipped with a variable-speed drive; a program timer was installed to permit automatic operation; and sample piping was provided to allow visual observation of the flow.

Small scum wells were provided in the common wall between every second tank and skimmings were to be pumped directly to the digesters by the sludge pumps. The piping system was arranged so that sludge could be drawn into the scum wells for observation from either the force main or the sludge sumps.

Sludge Characteristics

Little was known about the composition of the sludge other than that, in addition to the domestic solids, it would contain a variety of industrial wastes and would contain, seasonally, large quantities of fruit and vegetable canning wastes. It was predicted that ground water seepage would be high and that a portion of the sand and silt it carried would become a part of the sludge.

Force Main Design

Data on the flow of raw primary sludge in pipelines was found to be

* Presented at the 30th Annual Meeting of the California Sewage and Industrial Wastes Assn.; Stockton, Calif.; Apr. 23–26, 1958.

both meager and inconclusive. Published results of the best experimental work indicated the frictional resistance to the flow, for sludges containing six per cent solids, was approximately 1.5 times the value computed for water using a coefficient of 100 in the Hazen-Williams formula when the sludge velocity is 3 fps; and approximately equal to that for water when the velocity is 6 fps (1). For want of better information, the force main was sized to operate at velocities between 3 and 6 fps. To allow for the fact that the sludge was undigested and would at times be more concentrated, the pumping units were sized on the assumption that the frictional resistance would be four times that for water.

Raw Sludge Pump Selection

Two distinct classes of pumps were, and still are, commonly used for moving sewage sludge: the centrifugal pump and the reciprocating piston-type displacement pump. The relative merits of each class are matters on which designers and operators do not agree.

Centrifugal pumps were chosen in preference to piston-type displacement pumps because the latter are often noisy, require a great deal of operating attention, and are not readily removed for repairs because of their weight and size. Operating reports also indicated that when the sludge contained quantities of grit or other abrasive material frequent repacking and overhaul of pistons were required. Housekeeping and odor problems were also associated with the constant leakage of sludge from around the pistons and the cleaning of the ball check valves.

Visual Samplers

Soon after the plant was placed in operation, sampling devices consisting of lengths of 4-in. diameter pyrex pipe were installed on each of the raw sludge pumps and at other points where sludge samples are required. One end of the glass pipe is connected to the sludge piping by means of a quick-opening valve. Water for flushing and compressed air at a pressure slightly greater than the pipeline pressure are piped to the other end. A sample is obtained from the flow by opening the quick-opening valve and slowly exhausting the compressed air from the sampler. The collected sample can either be drained for analysis or returned to the flow without exposing the sludge to the atmosphere by repressuring the sampler with air. Operators can, with experience, very accurately estimate the concentration of the sludge by watching it flow into the sampler. Samplers of this type should be designed as pressure vessels, and should be properly guarded for the safety of operating personnel.

Operating Experience

Over-all Results

During the six years the plant has been in operation it has been possible to achieve the intended results with the original facilities. As shown in Table I, the sludge fed to the digesters has each year averaged better than six per cent total solids; the amount of operating labor required has not been excessive; and there have been no odor problems in connection with this phase of operations. However, it has been necessary to modify and augment the original installation because sludge quantities have been much greater than predicted and

TABLE I.—Raw Sludge Solids Concentration

Fiscal Year	Total Solids (%)		
	Yearly Avg	Max Mo.	Min Mo.
1953	7.6	9.3	6.4
1954	6.3	7.0	5.6
1955	6.3	7.1	5.9
1956	6.1	7.0	5.0
1957	6.3	6.6	5.8

grease, sand, and fine silt in the sludge have created operation and maintenance problems.

Grease

Ether soluble oils and greases comprise, on the average, 25 per cent of the sludge solids. This is not excessively high as compared with other plants of similar size, however, because the force main is buried in the ground, these materials separate from the sludge flow and deposit on the walls of the pipe. During the first month of operation grease deposits reduced the effective diameter of the 6-in. force main to less than 2 in. Even after the grease deposit was removed with augers and knives attached to power-operated sewer rods, the friction loss when pumping sludge containing six per cent total solids was twice the design value, or eight to ten times that for water. Experimental work by Brisbin (2) and others has since confirmed that friction losses, when pumping concentrated raw sludges, are of this order of magnitude. Because of the increased friction losses, and because the sludge quantities were greater than anticipated, it was necessary immediately to increase the horsepower of the sludge-pump drives, and to add a booster pump a short time later. The resulting increase in flow rate did not prevent the deposition of grease in the force main, but did lengthen the time between cleanings. The build-up was very gradual during the late spring and summer when the ground and sludge temperatures average 63 and 75°F, respectively. During the winter, when these temperatures drop as low as 53 and 60°F, the build-up was very rapid. At times it was necessary to clean the force main as often as three times a week. Attempts to remove or prevent the grease coating from forming by back-flushing with supernatant liquor, heated in the digester heaters to 100°F, were not successful.

Steam Generator

A search of literature disclosed that a similar problem at the Buffalo, N. Y. works had been solved by heating the pipeline with steam. Experimental work with a small steam-cleaning machine indicated that the grease deposit could be removed in this manner if sufficient heat was added to raise the temperature above 130°F.

A sludge-gas fired, fully automatic, forced recirculation-type steam-generator was installed so that its output of 100 boiler hp could be injected directly into the sludge force main near each sludge pump discharge.

Since installing the steam-generator the force main has been maintained at or near rated capacity by heating and flushing at intervals, the lengths of which vary with the season of the year. Except for the infrequent removal of stoppages caused by rags and trash, cleaning of the pipeline with sewer rods has been eliminated. Noise and vibration initially accompanied the direct injection of the steam into the pipeline. This was subsequently eliminated by the installation of a Venturi-type pipeline heater.

Sand and Silt

Material identifiable as sand and silt annually averages 17 per cent of the total, or 65 per cent of the fixed solids in the raw sludge, and during the winter season monthly averages have been as high as 40 per cent of the total, or 90 per cent of the fixed solids. Sieve analysis of samples of this material taken from the raw sludge and from deposits in the digesters disclosed that the average particle size is less than 0.20 mm, which is the smallest size particle that the grit chambers will normally intercept.

The sand and silt in the raw sludge have caused pump maintenance costs to be excessive. It wears the tips off of the impellers, quickly dulls cutting edges, and opens up the internal clearances of the pumps to the point

where they frequently clog with rags. Tramp metal is occasionally carried into the pumps with the sludge, where it lodges and causes twisted shafts and other damage. The high rotative speeds of the centrifugal pumps accelerate normal wear and cause increased damage by tramp metal.

During summer months these conditions have made it necessary to replace sludge pumps after an average of 800 hr of operation, which is equivalent to two replacements per year per sedimentation tank; and during the winter months after only 200 hr of operation, which is equivalent to eight replacements per year per tank. The cost of completely overhauling a pump, including removal from service and reinstallation, has averaged $218.

Attempts to decrease the frequency of sludge pump replacement and reduce repair cost included: removal of some of the cutting edges; hard-facing and chrome-plating the areas where wear was severest; and changing the material of some of the parts. These measures were only partly successful, and led to the investigation of other types of equipment.

Progressing-Cavity Pump

One of several types of pumping equipment considered during the course of this investigation was the helical-rotor, progressing-cavity pump. This pump, a modified screw-type pump, is simple in design and construction and has only two parts subject to wear, both of which can be replaced quickly and easily—desirable features from a maintenance standpoint. The delivery is uniform and the head-capacity relationship, like that for a piston pump, is nearly independent of the discharge head.

Progressing-cavity pumps are used in the process industries to handle sludges containing solids in suspension as large as 7/8-in. diameter, and to pump abrasive slurries. They have also been used in England to pump digested sewage sludge to vacuum filters, but the pumping of raw primary sludge which contains rags and trash had not been attempted as far as could be determined except in connection with experimental work by the Allegheny County (Pa.) Sanitary Authority (3). Some doubt existed that they would successfully handle raw primary sludges without excessive clogging caused by rags winding around the exposed rotating shaft in the suction cavity, and by sticks and trash accumulating in the bend at the pump inlet.

A progressing-cavity pump was borrowed from the manufacturer to determine if clogging would prevent its use for raw sludge at the East Bay works, where screens with 1-in. clear openings between bars are used to remove trash. It was temporarily installed in place of the original pump at the sedimentation tank which, because of its location, always receives the most rags and trash (Figure 1).

The test pump had a 6-in. suction and a 5-in. discharge and was V-belt driven by a variable-speed drive. The delivery could be varied from 80 to 160 gpm against a total head of 150 ft of water. It was equipped with an oil-resistant, synthetic-rubber stator and a chrome-plated tool-steel rotor, a combination of materials known to give good service under abrasive conditions.

A water seal was not installed on the packing gland which would be subjected to only the suction pressure, in this case 15 ft of water. An estimated annual saving in water cost of approximately $150 per pump would be realized if the water seal could be omitted successfully.

The suction cavity was inspected for rags once a day after the pump was first installed. Some rags were always found wrapped around the connecting link, but they did not build up to the point where the pump's performance was adversely affected. The inspection

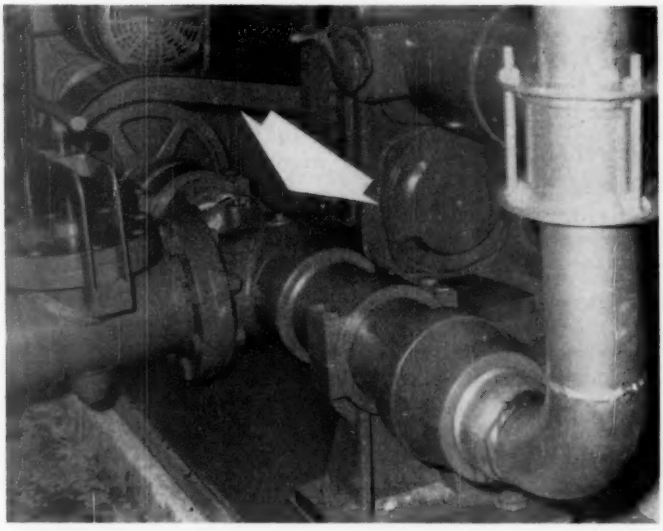

FIGURE 1.—Progressing-cavity pump installed at the East Bay works. Suction connection is to the left of the arrow; discharge is in the foreground.

frequency was therefore gradually lengthened, and finally eliminated after about two weeks of operation.

The test pump was disassembled for the first time after approximately 19 months' service to determine the cause of a sudden loss of capacity and accompanying vibration. It was found that a sharp object passing through the pump had gouged a piece from the rubber stator making replacement necessary. Although the rotor showed only nominal wear, it was thought advisable to strip and replate it. Total cost of the repairs was $140 and the down time to replace the stator and rotor was approximately two hours. This was substantially less than the cost of repairing one of the centrifugal-type pumps. Replacement of the stator, for the same reason, was again necessary after about six months' additional operation.

Operating experience with the progressing-cavity pump at the East Bay works may be summarized as follows: (a) Delivery is constant and nearly independent of the head or the concentration of the sludge, which is extremely heavy and laden with sand and silt during the winter, and cannery wastes during the fall. (b) Overhaul frequency, compared with the centrifugal units, has been reduced more than 50 per cent because of the low rotative speed and the combination of rubber and chrome-plated wearing parts. (c) There has been no evidence of scoring of the shaft in the packing gland that would indicate a water seal is necessary. (d) Rags accumulate on the exposed shaft in the suction cavity, but the pump does not require cleaning more often than the original pumps when in good condition. (e) The rubber stator is susceptible to damage from sharp metal objects; the use of a magnet and a metal trap ahead of the pump possibly would prevent this. (f) Clogging in the suction piping or loss of suction have not occurred because of the ability of the pump to prime itself and maintain its prime at suction lifts as high as 28 in. of vacuum.

Although the progressing-cavity

pump has been used successfully as a raw sludge pump at the East Bay plant, it needs much additional testing before it can be considered entirely satisfactory for this service.

Operating Routine

The following routine, developed and modified during six years of operation, is followed in the operation of the raw sludge pumping system.

1. The sludge collectors are operated continuously and the collected sludge is withdrawn from each of the sedimentation tanks at least once during each of the operating shifts to prevent septicity. The length of the pumping period varies with the season of the year, but averages about 30 min.

2. The sludge pumps are normally operated in pairs and are controlled automatically by the program-timer during the day and evening shifts, and manually during the morning shift to ensure that all of the day's accumulation of sludge has been removed. The concentration of the sludge leaving each tank is checked by the operator by means of the visual samplers before the pump is stopped. Skimmings are removed and pumped at the end of each sludge-pumping cycle.

3. The booster pump is operated in conjunction with all pumps except the three progressing-cavity pumps.

4. When it becomes necessary to remove the grease coating from the force main, the flow rate is reduced to 80 gpm and the sludge heated with steam to approximately 150°F. Several hours of operation at this rate of flow and temperature melt the grease deposit and restore the capacity of the force main.

Conclusions

On the basis of the material presented herein the following general conclusions appear to be justified:

1. Pumping raw sludge from batteries of sedimentation tanks directly to digestion systems or other disposal facilities is an economical procedure at large sewage treatment plants from both the capital-investment and operating-cost standpoints.

2. The solids concentration of raw sludges can be effectively controlled through the use of variable-speed pumps, visual samplers, and program timers.

3. The friction head, when pumping raw primary sewage sludge averaging six per cent solids, is approximately eight to ten times that for water.

4. The grease coatings which tend to form in raw sludge force mains can be effectively removed by injecting steam directly into the flow.

5. Raw primary sewage sludges can be pumped successfully with the larger progressing-cavity pumps if the sewage flow is properly screened prior to sedimentation.

Acknowledgment

The assistance of Gerson Chanin, Chief Sanitary Chemist, and G. H. Davis, Jr., Sewage Works Supervisor, in the preparation of this paper is gratefully acknowledged. The author is especially indebted to plant personnel for many valuable ideas and suggestions as to improvements and modifications of equipment and operating techniques.

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INTERESTING EXTRACTS FROM OPERATION REPORTS

"Behind an able man there are always other able men."—Chinese Proverb

Attention operators! It will be appreciated if copies of the annual reports of both large and small sewage and industrial waste treatment plants are sent to the Federation office for abstracting in this section of the Journal. Please direct annual reports to: The Operator's Corner, Federation of Sewage and Industrial Wastes Associations, 4435 Wisconsin Ave., N.W., Washington 16, D. C.

Annual Report of the Division of Sewage Disposal, Cleveland, Ohio, for 1955 *

The operating revenues for the Division of Sewage Disposal, Cleveland, Ohio, were higher than in 1954 as a result of continued increase in water consumption which is the basis for the service charge. However, the financial condition of the Division has not improved and is very unsatisfactory. The net income was considerably less than the income derived from interest earnings; therefore, without the income from other financial sources the Division would have operated at a loss. This condition has existed for the past three years and will become increasingly serious when bond investments are used for construction.

Some relief will be obtained when sewage from a suburban area (Hilltop) is diverted from the Euclid, Ohio, plant to the Easterly plant. Eventually, it will become necessary to increase the service charge.

The three Cleveland treatment plants treated a record total of 71,647 mil gal of raw sewage in 1955 for an average of 196 mgd.

Report on the Operation and Maintenance of the Easterly Sewage Treatment Plant, Cleveland, Ohio, for 1955 †

JOHN J. WIRTS, *Superintendent*

The Easterly treatment plant provides activated sludge treatment to 52 per cent (102 mgd) of the Cleveland sewage flow. It is the largest of the three plants and is located on the shore of Lake Erie in a Class "A" residential area. The water front is a popular boating and bathing area.

Wear caused by grit is evident in all comminutors. Bearing failure in the 54-in. comminutor was determined to be caused by overload in thrust and not by bearing defect. Tandem mounting instead of back-to-back mounting will be tried.

Pumping of raw sludge to the Southerly plant for digestion was satisfactory. The volume was considerably less than in 1954. Blockages and repacking of the pumps have been reduced through the use of a Swartwout seal water system. The seal water to each pump is regulated according to a preset differential. Adjustment of the packing gland depends on operating experience and varies with the type of sleeve.

Stainless steel sleeves have given good service and stand abuse from over-adjustment of the gland and mal-

* For last previous extract see THIS JOURNAL, **28**, 12 1515 (Dec. 1956).

† For last previous extract see THIS JOURNAL, **28**, 12, 1516 (Dec. 1956).

TABLE I.—Air Diffuser Cleaning Data

Item	Aeration Tank					
	No. 3		No. 7		No. 10	
	Before Cleaning	After Cleaning	Before Cleaning	After Cleaning	Before Cleaning	After Cleaning
Service (mo.)	—	27	—	47	—	50
Cone valve opening	⅜ to ½	½	Wide	½	Wide	½
Pressure (psi)	6.6	6.7	7.1	6.6	7.2	6.3
Air (cu ft/min)	2,500	3,400	1,200	3,400	1,100	3,800

adjustment of the seal water. Experience with monel sleeves has been uneven; satisfactory service has ranged from six weeks to more than nine months. Stellite sleeves do not wear well and split in two.

The force main to the Southerly plant was cleaned eight times without difficulty. Heavy discharges of grease were reported at all blow-off stations.

Diffuser Cleaning

An experimental method of cleaning the activated sludge air diffuser plates was tried. A solution of phosphate under 400 psi pressure was sprayed

TABLE II.—Summary of Operating Data, Easterly Plant, Cleveland, Ohio, for 1955

Item	Average
Raw sewage flow (mgd)	102.2
Settled sewage flow (mgd)	97.9
Grit removed (cu ft/mil gal)	2.7
Screenings (cu ft/mil gal)	0.16
Suspended solids (ppm):	
Raw	196
Settled	111
Effluent	13.6
Removed (%)	92.4
BOD (ppm):	
Raw	135
Settled	81
Effluent	13.2
Removed (%)	90.2
Oxygen consumed (ppm):	
Raw	78
Settled	56
Effluent	19
Reduction (%)	75.2
Dissolved oxygen (ppm)*:	
Presettled raw sewage	2.4
Aerator influent	2.1
Aerator effluent	2.9
Final effluent	3.0
Ammonia (ppm):	
Raw	15.5
Settled	9.1
Effluent	9.1
Nitrite, effluent (ppm)	0.4
Nitrate, effluent (ppm)	4.3
Sludge pumped to Southerly plant, total (mil gal)	178.02
Moisture (%)	97.0
Activated sludge:	
Total solids (ppm)	5,208
Volatile solids (%)	61.1
Mixed liquor susp. solids (ppm)	1,361
Sludge index (ml/g)	78
Air (cu ft/gal, settled sewage)	0.76
Returned sludge (%)	27.4
Post-chlorination†:	
Days applied, total	95
Application rate (ppm)	3.5
Residual (ppm)	2.4‡
Bacterial count; agar plates at 37½°C (1,000/ml)¶:	
Raw	35.7
Effluent	3.2
Reduction (%)	91.0
Presumptive *B. coli* (1,000/ml)¶:	
Raw	113
Effluent	2.4
Reduction (%)	97.9
Plant costs ($/mil gal):	
Operation and maintenance	19.03
Administration	15.64
Total	34.67

* Average of determinations made every 4 hr.
† Contact time 5 min.
‡ Inaccurate color standards.
¶ Averages of Monday and Wednesday catch samples.

over the diffusers. One to three applications were made depending on the length of time the diffusers were in service. Between applications the diffusers were covered with water and periodically surged with air. This treatment was followed by application of silicone which is standard practice. Tentative data are given in Table I.

The power bill was 13 per cent less than in 1954 and 9.8 per cent less than in 1953. Lower pressures compatible with more uniform air distribution are partially responsible for the saving. Foam on the aeration and final settling tanks has been troublesome.

Operation data for 1955 are summarized in Table II.

Report on the Operation and Maintenance of the Westerly Sewage Treatment Plant, Cleveland, Ohio, for 1955 *

JOHN O. BARRETT, *Superintendent*

The Westerly sewage treatment plant provides primary treatment for about 17 per cent (34 mgd) of the Cleveland sewage flow. Located east of Edgewater Park yacht basin, the plant requires careful operation to control odors. Post- and pre-chlorination are practiced during the summer.

This plant serves a diversified industrial section, where meat processing plants contribute the most difficult waste to treat. Furthermore, the collection system is of the combined type. Flows in excess of 72 mgd bypass the plant. The population equivalent is about 340,000.

Contracts for new construction work amounting to $810,000 were let in 1955. Included were two grit removal units to replace existing grit chambers, a grit building to house grit loading equipment, mechanical rakes and screenings grinders to replace hand-raked screens, a pre-aeration tank, and miscellaneous items.

Sedimentation and Digestion

Sedimentation is accomplished in the old Imhoff tanks. Slots were kept open by hosing after the tanks were pumped down. The suspended solids load was considerably less than the previous year.

Gas vent lids were replaced or repaired. Considerable spalling of the concrete necessitated numerous patches on the Imhoff tanks. The polyvinyl chloride 1-in. pipe risers installed on the raw water spray system last year appeared to be in perfect condition, thus solving a corrosion problem.

Five of the six floating cover digesters were operated as primary tanks. The sixth was used as an unheated sludge storage tank for purposes of giving the staff operating variety and experience.

The annual program of cleaning the digesters to remove scum, which is a troublesome operating problem, was started in March. Scum thicknesses as great as 12.5 ft were observed. Two digesters were cleaned twice.

Scum control with gas recirculation was continued on a trial basis. Results to date are not sufficiently conclusive to warrant a permanent installation. Gas production has not been appreciably increased, and the reduction in scum thickness may be partially attributed to compaction.

The estimated power cost for one year of gas recirculation was in excess of $800, compared to a labor cost of approximately $200 for removing scum by pumping the digester down.

The quality and quantity of the raw sludge were lower than during the preceding years and gas production was down 9.8 per cent.

After many years of cleaning out digesters, an experienced attendant

* For last previous extract see THIS JOURNAL, **28**, 12, 1518 (Dec. 1956).

Table III.—Summary of Operating Data, Westerly Plant, Cleveland, Ohio, for the Year 1955

Item	Average
Raw sewage flow (mgd)	34.4
Grit removed (cu ft/mil gal)	2.52
Screenings (cu ft/mil gal)	1.49
Suspended solids (ppm):	
Raw	256
Settled	181
Removed (%)	29.4
BOD (ppm):	
Raw	183
Settled	137
Removed (%)	25.1
Oxygen consumed (ppm):	
Raw	137
Settled	116
Reduction (%)	15.7
Total bacteria (1,000/ml):	
Raw	2,463
Settled	1,111
Reduction (%)	54.9
Presumptive *B. coli* (1,000/ml):	
Raw	435
Settled	105
Reduction (%)	75.9
Pre-chlorination:	
Days operated	88.3
Dose (ppm)	5.03
Post-chlorination:	
Days operated	84.3
Dose (ppm)	8.54
Residual (ppm)	1.47
Raw sludge to digesters:	
Number of additions per month	62
Temperature (°F)	65
Volatile solids (%)	68.9
Total solids (%)	6.18
pH	6.2
Alkalinity as $CaCO_3$ (ppm)	610
Digester supernatant:	
Total solids (%)	0.82
Volatile solids (%)	53.4
pH	8.0
Alkalinity as $CaCO_3$ (ppm)	1,940

Item	Average
Gas production:	
Daily (cu ft)	133,700
Cu ft/lb volatile solids	6.9
CO_2 (%)	26.9
Gas utilization (%):	
Digester heaters	31.8
Building heaters	22.1
Incinerators	24.6
Wasted	21.5
Digested sludge vacuum filtered:	
Total solids (lb/mo)	469,900
Total solids (%)	7.42
Volatile solids (%)	54.5
pH	7.9
Alkalinity as $CaCO_3$ (ppm)	1,920
Chemical dosage for vacuum filtration (%):	
Ferric chloride	3.04
Lime	14.8
Calcium oxide	13.1
Sludge filtration:	
Filter cake:	
Total (tons)	9,624
Moisture (%)	65.5
Volatile solids (%)	46.4
Rate (dry psf/hr)	3.08
Cake/hr (tons)	0.74
Cloth life (hr)	182
Sludge filter cake:	
Incinerated (tons/mo)	294
Tons per incinerator hour	0.92
Soil conditioner (tons)	6,095
Incineration:	
Fuel oil used:	
Gal/ton of filter cake	0.99
Gal/ton of dry solids	2.86
Gas used:	
Cu ft/ton of filter cake	1,082
Cu ft/ton of dry solids	3,134
Plant costs ($/mil gal):	
Operation and maintenance	15.47
Administration	15.65
Total	31.12

slipped on the grease-coated sloping floor and broke his leg. Carelessness was not involved, but the need for extraordinary precautions was emphasized.

Sludge Disposal

Filter cake production decreased 26.2 per cent because of the decrease in solids. Maintenance and operation of the filter equipment were routine, and most repairs were due to normal wear.

Cake incineration was erratic because of the variable quantities of scum contained in the cake. At times the cake contains an abundance of grease and highly volatile material which causes it to burn on the upper hearths. At other times the cake hardens and resists burning. When these conditions exist, incineration capacity is reduced approximately 50 per cent.

An accumulation of grease in the pre-heater, and excessive temperatures

caused by highly volatile scum, resulted in a fire that melted sections of the heat exchanger grid.

Efforts are being made to conduct an education program among the industrial waste contributors, particularly the meat processors. Good housekeeping by this industry would do much to decrease the operating problems.

Operating data for 1955 are summarized in Table III.

Report on the Operation and Maintenance of the Southerly Sewage Treatment Plant, Cleveland, Ohio, for 1955 *

WALTER E. GERDEL, *Superintendent*

The Southerly sewage treatment plant provides primary treatment for about 30 per cent (60 mgd) of the Cleveland sewage flow. Both sanitary and industrial wastes are handled. Flow in 1955 was 27 per cent greater than the previous year, as a result of increased rainfall and the connection of a large interceptor. The maximum daily flow was 123 mil gal. The treatment facilities provide aeration for only 36 per cent of the flow; the remainder is given primary treatment.

Additonal sludge digestion, elutriation, and aeration units were completed during 1955. Work started on additional incinerator and vacuum filter capacity. Capacity of the plant is being increased from 36 mgd to 68 mgd for complete treatment by activated sludge. Primary treatment can be given to 170 mgd. New settling tanks were completed in 1954.

A gas explosion resulting from contractor activities occurred in the sludge pump building during connection of a high pressure gas system. There were no injuries.

Activated Sludge

Aeration Tanks 1 and 2 were lengthened to provide 4-hr detention at 22 mgd. Excessive clogging of the air diffusers was caused principally by formation of precipitated iron hydrate in the tubes. Analysis of the sewage revealed that slugs of pickle liquor of high strength were received during certain periods of the day. Starting in August, the iron content of the settled sewage was checked frequently and flow to the aeration tanks was reduced when the iron content exceeded 10 ppm.

The clogging problem became so acute and required so much labor that the first five swing diffusers were replaced with coarse bubble-type air units. A number of experimental diffusers were fabricated at the plant and installed. Of special interest are a thin-walled stainless steel tube and a thin-walled plastic tube with various size air holes.

Foaming problems increased, although the exact cause is not known. At times it seriously interfered with air diffuser maintenance, and provided unsightly, odorous, and unsafe conditions.

Noise from the main air header was very disturbing. Adjustment of the butterfly valves was helpful; however, conditions of operation would change suddenly and it was impossible to keep the valves adjusted. The problem is one for expert study.

Engine oil leakage from threaded pipe joints increased as the new blowers continued in operation. The condition is hazardous and inimical to good housekeeping. A welded pipe system may need to be installed.

Sludge Handling

The increased volume of waste activated sludge made it necessary to operate the sludge concentration tanks on a continuous basis.

* For last previous extract see THIS JOURNAL, **28**, 12, 1521 (Dec. 1956).

TABLE IV.—Summary of Operating Data, Southerly Plant, Cleveland, Ohio, for the Year 1955

Item	Average
Raw sewage flow (mgd)	59.6
Detritor grit (cu ft/mil gal)	1.26
Volatile (%)	46.4
Flow distribution (%):	
Aeration unit	36.3
Bypassing sec. treat.	63.7
Suspended solids (ppm):	
Raw	224
Primary effluent	97
Removal, primary (%)	56.7
Aerator influent	86
Aerator effluent	12
Removal, aerator (%)	85.5
Dissolved oxygen (ppm):	
Raw	5.5
Primary effluent	4.7
Aerator effluent	1.0
River above plant	6.6
River below plant	6.4
BOD (ppm):	
Raw	143
Primary effluent	68
Removal, primary (%)	51.4
Aerator effluent	6
Removal, aerator (%)	89.9
River above plant	15
River below plant	24
Combined effluent over-all reduction (%):	
Suspended solids	72.5
BOD	67.9
Sulfates, raw sewage (ppm)	237
Digester operation:	
Raw sludge:	
Volume, total (mil gal)	282.1
Easterly plant (%)	63.8
Southerly plant (%)	36.2
Dry solids (%)	3.5
Volatile solids (%)	63.6
Primary digested sludge:	
Volume, total (mil gal)	49.24
Dry solids, total (mil lb)	21.67
Volatile solids, total (mil lb)	9.91
Total solids (%)	5.1
Volatile solids (%)	45.7
Alkalinity (ppm)	2,600
pH	7.6
Secondary digested sludge:	
Volume, total (mil gal)	17.15
Total solids (%)	7.0
Volatile solids (%)	45.9
Alkalinity (ppm)	2,970
pH	7.6
Supernatant:	
Volume, total (mil gal)	211.46
Total solids (%)	1.22
Volatile solids (%)	52.7
Suspended solids (ppm)	1,492
Gas production:	
Daily production (1,000 cu ft)	1,919.6
Cu ft/lb volatile solids	7.0
CO_2 (%)	33.5
Btu/cu ft (gross)	602
Gas utilization (%):	
Digester heating	29.6
Incinerators	9.2
Gas engines	15.1
Building heat and misc.	11.0
Wasted	35.1
Vacuum filtration:	
Filtered, total (mg)	52.51
Dry solids, total (mil lb)	25.01
Chemicals used (%):	
Ferric chloride	3.8
Lime	13.2
Filter cake:	
Dry solids, total (tons)	16,684
Solids (%)	27.8
Volatile solids (%)	38.2
Rate (lb dry solids/sq ft/hr)	3.06
Cloth life (hr)	257
Sludge incineration:	
Tons/mo, wet	4,847
Tons/incinerator day	83
Btu/lb volatile solids	11,781
Moisture (%)	72.3
Volatile (%)	38.2
Plant costs ($/mil gal):	
Operation and maintenance	15.63
Administration	15.67
Total	31.30

The 18 floating-cover digesters were operated as primary tanks. The 12 old Imhoff tanks served as secondary digesters and received only primary tank supernatant. A gear pump was used to remove approximately 100,000 gal of oil from the surfaces of the secondary digesters. The oil was given to a used oil dealer for road oil. Scum in connection with the oil removal made the operation expensive.

The digester hot water boilers were improved to eliminate short circuiting. The heat transfer rate in the sludge heaters decreased because of the build-up of scale in the sludge tubes. Removal of scale is expensive and time consuming. This problem needs further study.

After correction of a bearing failure, the new elutriation tank performed most satisfactorily. The spray

water system and scum removal piping are a considerable help in removing scum. All elutriation-unit scum is pumped to the secondary digestion tanks.

Wash water settling basins and screens were placed in operation in May. Results from the use of these new facilities are good.

Sludge Disposal

Vacuum filtration of the digested sludge was normal. Bucket elevators and chemical feeding equipment required considerable maintenance. The stainless steel filtrate pump operated satisfactorily.

Sludge cake is disposed of by incineration. Smoke difficulties were experienced, particularly during the summer. The incinerators and ash system required a great deal of work. Ash system improvements were started in December.

Plant Performance

The over-all removals of suspended solids and BOD were appreciably better than during previous years. This reflects the effect of the new aeration facilities and other units placed in operation in 1954 and 1955.

The appearance of the plant grounds was vastly improved by grading and grassing. A dedication ceremony and open house for the new facilities were held in October.

Operating and maintenance costs increased approximately $47,500 over 1954.

Operation data for 1955 are summarized in Table IV.

Industrial Wastes Control Unit

JOHN R. WOLFS, *Engineer-in-Charge*

Industrial waste problems have received increased attention as their seriousness became more apparent. The Industrial Wastes Control Unit was created in September 1954 and organized its program during 1955.

The problem of treating acid wastes is one of the most troublesome. Nineteen companies were notified to stop the discharge of this waste to the sewers. Outcome of this enforcement depends on the results of a pilot-plant installation of the Blaw-Knox Ruthner Process for treating the waste, at Niles, Ohio.

Various phases of the waste control program are inspection and testing of sewer flows, stream and lake pollution sampling, and general public relations with industry.

The need for expanded services of this section is very apparent and its establishment has been an important step forward in improving the operation and administration of the sewage disposal program in Cleveland.

DIGESTER START-UP AT COBOURG, ONTARIO

BY CHARLES HICKS

Superintendent, Cobourg Sewage Treatment Plant, Cobourg, Ont., Canada

During the winter of 1956 the digester at the Cobourg, Ont., sewage treatment plant was inspected and cleaned. Because of the cold weather it took approximately two months to complete the job. The digester has a 50-ft diameter and 19-ft side-water depth. It is equipped with two sets of internal heating coils, two internal mixers of the draft-tube type, recirculation facilities, and a temperature control device located at about mid-depth. The unit has a fixed cover.

The digester had been in continuous

service for six years prior to cleaning. Inspection revealed that only about 12 in. of scum and 2 cu. yd of grit and sand had accumulated.

In starting the unit, about 12 ft of fresh water and 500 lb of lime were added. The auxiliary boiler was then fired and the temperature of the water was raised to 90°F. No seed sludge was available. For the first week sludge from the primary clarifier was added for two 10-min periods each day. Digester contents were recirculated for about 6 hr each day. The second week raw sludge pumping was increased to two 20-min periods each day. By the 16th day sufficient gas was available to fire the boiler. Care was taken to add only thick sludge during the start-up.

Normal digester operation over the years has consisted of maintenance of a liquid temperature of about 90°F, sludge recirculation for about 4 hr a day, and internal mixing for three 2-hr periods each day. On the basis of past experience this schedule appears to be a good one.

TIPS AND QUIPS

Sewage Flocculation *

A few months ago at the Little Miami Sewage Works, Cincinnati, Ohio, preliminary tests were made to determine if operation of the paddle wheel agitators would cause better settling efficiencies. In these tests sewage was pumped from the plant aeration channel to two 50-gal plastic drums. The contents of one drum were agitated slowly with a wooden paddle for 20 min. No chemicals were added. After stirring, the contents were allowed to settle for 2 hr. The second drum of sewage was not stirred but was allowed to settle for 2 hr 20 min. Tests showed that suspended solids removal was 14 per cent better for the stirred sewage.

While it is doubtful that comparable increases can be obtained on a plant scale, the tests were sufficiently encouraging to warrant the use of the flocculators for full-scale evaluation.

I have no technical and no university education, and have just had to pick up a few things as I went along.

WINSTON CHURCHILL

* Bulletin of the Sewage Disposal Section, Cincinnati, Ohio, Sept. 1958.

Day in Court †

A few months ago a court decision was handed down concerning the discharge of treated sewage by the community of Rolla, N. Dak. Rolla is a community of 1200 people that has recognized its responsibility in the matter of pollution abatement. A satisfactory lagoon system was constructed there about four years ago. During the past year a downstream landowner sought to prevent the town from discharging its well-treated effluent to the watercourse which flows through his land and, if possible, secure damages for the discharge of the treated wastes. The Rolla installation had met all requirements of law in regard to plan approval and operation. After hearing the testimony the judge ruled in favor of the town, stating that Rolla had the right to discharge sewage into a defined watercourse, providing adequate treatment was provided.

Intelligent ignorance is the first requirement in research.

Charles F. Kettering

† *Official Bulletin*, North Dakota Water and Sewage Works Conf., **26**, 3, 1 (1958).

Reactor Wastes

A large-scale waste calcination pilot plant is now being built at the National Reactor Testing Station, Idaho. At present, when used nuclear fuels are removed from reactors and processed to recover valuable fissionable materials for re-use, the highly radioactive and corrosive liquid wastes that result from the solvent extraction process are stored in underground steel tanks.

The new process converts the liquid wastes to solid form and reduces their volume to about one-seventh of the original bulk. It is hoped that it will also make the waste less corrosive and correspondingly easier to store. The process, called calcination, involves evaporating the water, decomposing the nitric acid to oxides of nitrogen, and converting aluminum nitrate to aluminum oxide. The calcination process yields a granular solid alumina product containing all fission products removed from the fuels except those contained in the dust entrained in the calciner fluidizing air. These products are removed by scrubbing and filtration techniques. A portion of the ruthenium volatilizes in the calciner, and is separated by adsorption. Since some of the highly radioactive fission products must decay for periods as long as 800 years before they can be safely discharged to water and air, the value of this process which "fixes" the radioactivity in a less mobile form is immediately evident.

The calciner is a cylindrical vessel containing at steady state a bed of granular aluminum oxide consisting of the product obtained from the evaporation and calcination of the waste solution. The bed is supported on a perforated or porous plate which serves as a gas distributor. Preheated air is passed upward through the plate to fluidize the bed and agitate the solids. The entire mass behaves as a vigorously boiling liquid.

Additional heat is supplied to the solid particles (aluminum oxide) through heat transfer tubes within the bed itself. The bed temperature is maintained in the range of 400 to 500°C. The waste solution is injected into the bed through several spray nozzles spaced around the calciner. The liquid droplets, upon contacting the hot solid particles, are flash dried and calcined to oxides.

The calcination facilities are designed to process aluminum nitrate wastes that have decayed at least 200 days after discharge from the reactor. Initial operation will be with two-year-old waste; because of longer radioactive decay it generates less heat and thus will facilitate the first observations made on solid waste materials. The plant will be capable of handling 1 gpm of liquid wastes.

The radioactive nature of the materials handled makes it necessary to house the process equipment in concrete cells to shield operating personnel. The possibility of spreading cell contamination is reduced considerably by designing the facility for negative pressure operation throughout. Cells are arranged to facilitate processing, maintenance, and subsequent modification for process improvement.

This type of treatment will not impair the preliminary or subsequent separation of special fission product values (radioisotopes) for industrial utilization.

Research work for the process is now being conducted by the Phillips Petroleum Co. and the Argonne National Laboratory. This work is still in progress, and most process uncertainties will be resolved before the plant begins to operate. However, the fundamental purpose of the plant will be to demonstrate feasibility on an engineering scale. Process development will continue during plant shakedown and operation so as to allow maximum utilization of new technology.

Editorial

YOUR JOURNAL IN 1959

Nearly a generation ago, it was the slogan of a prominent automobile manufacturer to have "constant improvement, but no yearly models." Such a slogan could well be used for THIS JOURNAL, though the corresponding volume and calendar year make changes starting with the January issue particularly inviting.

Many readers may have already observed the new position of the contents page in this number. Instead of being the second page before the lead technical article, this has been moved to the second page after the inside front cover. This change has been made because of complaints that the contents page was not easily found. Certainly as the front advertising section varied, its former position changed with it. Now it will be constantly related to the front cover, just as the list of advertisers and professional card holders are related to the back cover. The understanding cooperation of the advertisers whose regular positions were affected by this shift is greatly appreciated. What is your reaction to this change? We hope you will consider it an improvement.

The Year 1959 promises to bring many new Federation organization developments, as given in the account of Detroit Board Meetings in the December 1958 number of THIS JOURNAL. With the most important place the Journal has in Federation responsibilities, some will be reflected in Journal content and organization.

A significant step is included in the list of revised abbreviations on pages 121 and 122. These will replace those given in the January 1958 issue. The new list is longer and includes additional expressions made desirable by Manual of Practice No. 6, *Units of Expression for Wastes and Waste Treatment*. While all units in the Manual are not included, the fundamental parts are given so that the combined value of standard units and abbreviations is now achieved.

The revised Manual of Practice No. 1, the Federation Safety Manual, under the Title, *Safety in Wastewater Works*, is at last being made available. Complete details will be given in February. It is hoped that the publication of Manual of Practice No. 8, *Sewage Treatment Plant Design*, will also be announced next month. This authoritative manual has been prepared cooperatively with the Sanitary Engineering Division of the American Society of Civil Engineers.

In coming issues, the added time now being given to the "Operator's Corner" will bring readers more of this most valuable material. At times it has seemed that the material printed in this section could be extended if its title could be changed to enlarge the scope. All material now used would continue to be used in the "Corner," but other experiences such as those of sewer system maintenance, the works laboratory, and more industrial waste plant operation would be added.

The Editorial Staff is devoted to making the Federation Journal one of service and greatest value to the readers, primarily Federation members. By your criticism and comment you will help this aim of constant improvement and you will help attain the high goals set for the Federation in 1959.

R.E.F.

JOURNAL ABBREVIATIONS

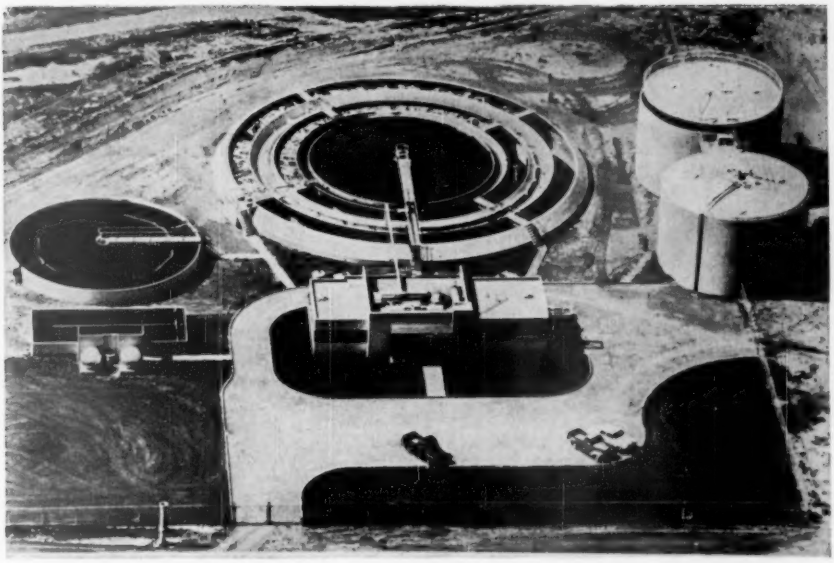
The following is a revised and extended list of abbreviations now used in SEWAGE AND INDUSTRIAL WASTES. The last previous list appeared in THIS JOURNAL, **30**, 1, 119 (Jan. 1958). Again, the abbreviations generally follow those published by the American Standards Association (ASA), as originally approved in 1941,* and agree for the most part with those in use by the *Journal American Water Works Association.*

As a further convenience, the Journal, by use, is endorsing the slash (/) as a substitute for the word "per" in combinations of fundamental units wherein the individual unit abbreviations are established but the combination is not. An example is the expression, "pounds per day per 1,000 cubic feet." This may be expressed as lb/day/1,000 cu ft. Thus, by using these fundamental combinations, abbreviations may be established for many other units including the units given in the Federation Manual of Practice No. 6, *Units of Expression for Wastes and Waste Treatment.*

acre-foot ..... acre-ft	degree (s) Fahrenheit ..... °F
alternating-current (adj.) ..... a-c	diameter ..... diam
after noon ..... PM	direct-current (adj.) ..... d-c
ampere (s) ..... amp	dissolved oxygen ..... DO
ampere-hour (s) ..... amp-hr	dissolved solids ..... DS
atmosphere (s) ..... atm	electromotive force ..... emf
average ..... avg	feet per day ..... fpd
barrel (s) ..... bbl	feet per hour ..... fph
Baumé ..... Bé	feet per minute ..... fpm
before noon ..... AM	feet per second ..... fps
billion gallons ..... bil gal	foot (feet) ..... ft
biochemical oxygen demand ..... BOD	foot-candle (s) ..... ft-c
brake horsepower ..... bhp	gallon (s) ..... gal
British thermal unit ..... Btu	gallons per day ..... gpd
bushel (s) ..... bu	gallons per day per acre .... gpd/acre
calorie (s) ..... cal	gallons per day per capita ... gpd/cap
capita ..... cap	gallons per day per square foot gpd/sq ft
centimeter (s) ..... cm	gallons per hour ..... gph
counts per minute ..... cpm	gallons per minute ..... gpm
counts per second ..... cps	gallons per second ..... gps
cubic feet per day ..... cfd	gram ..... g
cubic feet per hour ..... cfh	grams per liter ..... g/l
cubic feet per minute ..... cfm	horsepower ..... hp
cubic feet per second ..... cfs	horsepower-hour (s) ..... hp-hr
cubic foot (feet) ..... cu ft	hour (s) ..... hr
cubic inch (es) ..... cu in.	inch (es) ..... in.
cubic meter (s) ..... cu m	inches per second ..... ips
cubic yard (s) ..... cu yd	indicated horsepower ..... ihp
degrees (s) ..... deg	inside diameter ..... ID
degree (s) Centigrade ..... °C	

* "Abbreviations for Scientific and Engineering Terms." American Society of Mechanical Engineers, 29 West 39th Street, New York 18, N. Y. Price $0.50.

kilocalorie (s) ..... kcal
kilocycle (s) ..... kc
kilogram (s) ..... kg
kilometer (s) ..... km
kilovolt (s) ..... kv
kilovolt-ampere (s) ..... kva
kilowatt (s) ..... kw
kilowatthour (s) ..... kwhr
linear foot (feet) ..... lin ft
liter (s) l
logarithm (common) ..... log
logarithm (natural) ..... $\log_e$ or ln
maximum ..... max
maximum permissible concentration ..... MPC
median tolerance limit ..... TL_m
meter (s) ..... m
microcurie (s) ..... μc
microgram (s) ..... μg
microgram (s) per liter ..... $\mu g/l$
micromicrocurie (s) ..... $\mu\mu c$
micromicron (s) ..... $\mu\mu$
micron (s) ..... μ
mile (s) ..... spell out
miles per hour (s) ..... mph
milliampere (s) ..... ma
millicurie (s) ..... mc
milliequivalent (s) ..... me
milliequivalents per liter ..... me/l
milligram (s) ..... mg
milligrams per liter ..... mg/l
milliliter (s) ..... ml
milliliter (s) per liter ..... ml/l
millimeter (s) ..... mm
millimicrogram (s) ..... $m\mu g$
millimicron (s) ..... $m\mu$
million electron-volts ..... Mev
million gallons ..... mil gal
million gallons per day ..... mgd
million gallons per day per acre ..... mgd/acre
milliroentgens ..... mr
millivolt (s) ..... mv
minimum and minute (s) ..... min
molar (concentration) ..... M
molecular weight ..... mol wt
most probable number ..... MPN
normal (concentration) ..... N
number (s) ..... No.
ortho-tolidine ..... OT
ortho-tolidine-arsenite ..... OTA
ounce (s) ..... oz
outside diameter ..... OD
oxidation-reduction potential ..... ORP
oxygen consumed ..... OC
parts per billion ..... ppb
parts per million ..... ppm
parts per thousand ..... ppt
pound (s) ..... lb
pounds per acre ..... lb/acre
pounds per acre-foot ..... lb/acre-ft
pounds per day per acre ..... lb/day/acre
pounds per day per cubic foot ..... lb/day/cu ft
pounds per square foot ..... psf
pounds per square foot per hour ..... psf/hr
pounds per square inch ..... psi
pounds per square inch absolute ..... psia
pounds per thousand cubic feet ..... lb/1,000 cu ft
quart (s) ..... qt
radiation absorbed dose ..... rad
revolutions per minute ..... rpm
revolutions per second ..... rps
roentgen (s) ..... r
roentgen equivalent, man ..... rem
roentgen equivalent, physical ..... rep
second (s) ..... sec
sludge density index ..... SDI
sludge volume index ..... SVI
specific gravity ..... sp gr
specific heat ..... sp ht
square ..... sq
square centimeter (s) ..... sq cm
square foot (feet) ..... sq ft
square feet per capita ..... sq ft/cap
square inch (es) ..... sq in.
suspended solids ..... SS
total solids ..... TS
total suspended solids ..... TSS
total volatile solids ..... TVS
volatile solids ..... VS
volatile suspended solids ..... VSS
volt (s) v
volt-ampere (s) ..... va
watt (s) ..... w
watthour (s) ..... whr
week (s) ..... wk
yard (s) ..... yd
year (s) ..... yr



Engineers—Currie Engineering Company

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Proceedings of Member Associations

ROCKY MOUNTAIN SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The 22nd Annual Meeting of Rocky Mountain Sewage and Industrial Wastes Association was held, in conjunction with the Annual Meeting of the Rocky Mountain Section of the AWWA, at the Cosmopolitan Hotel, Denver, Colo., September 15–17, 1958. Registration totaled 114.

The program included the following papers of particular interest.

"Starting a Digester at the New Boulder Sewage Treatment Plant," by Ernest Hamilton, Boulder, Colo.

"Densludge Digestion," by Edward Thoits, Dorr-Oliver, Inc.

"Criteria for the Study of the Worth of an Acre-Foot of Water," by Arthur E. Williamson, Wyoming Department of Health.

"A Simplified Automatic Control System," by Curtis M. Clark, Foreman of the Aurora Water and Sanitation Department.

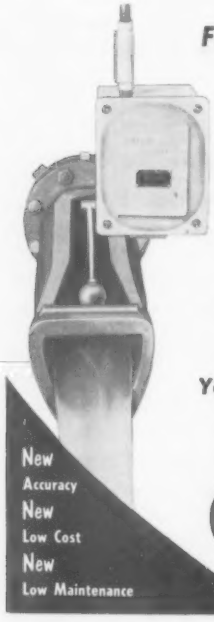
"The Role of the Chemical Engineer in Industrial Waste Treatment," by Ronald West, Boulder, Colo.

"The Role of the Civil Engineer in Industrial Waste Treatment," by John W. Clark, Las Cruces, N. Mex.

The program also included a panel discussion on types and applications of package plants.

At the Annual Business Meeting, the following officers were elected:

(*Continued on page 26a*)



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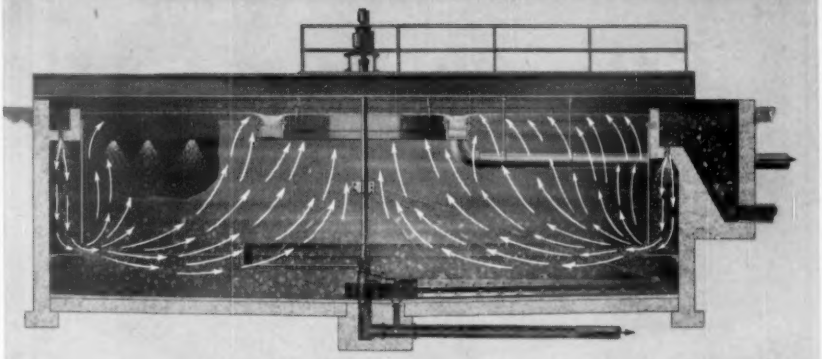

Cutaway view of Rex Rim-Flo.

Simplified cutaway view of Rex Rim-Flo illustrating flow patterns.

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SOUTH DAKOTA WATER AND SEWAGE WORKS CONFERENCE

The 24th Annual Meeting of the South Dakota Water and Sewage Works Conference was held at the Franklin Hotel, Deadwood, South Dakota, September 17–19, 1958. Registration for the meeting totaled 106.

The technical program was opened by an address from FSIWA Vice-President William D. Hatfield. This was followed by a panel discussion on "Water and Sewage Problems in Recreational Areas."

There was also a panel discussion on the topic, "Public Relations Related to Water and Sewage Works."

The following papers were presented:

"Water and Sewage Problems in Wyoming," by Arthur E. Williamson.

"Training and Certification Program at Sioux Falls," by James Cox.

"Radiation and Public Health," by George Jacobson and Don G. Kurvink.

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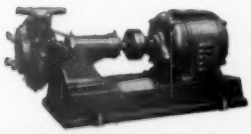

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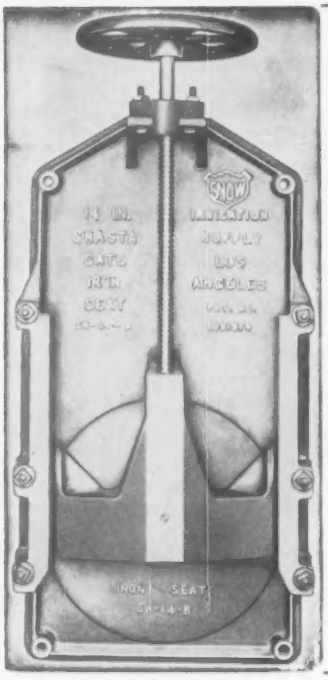

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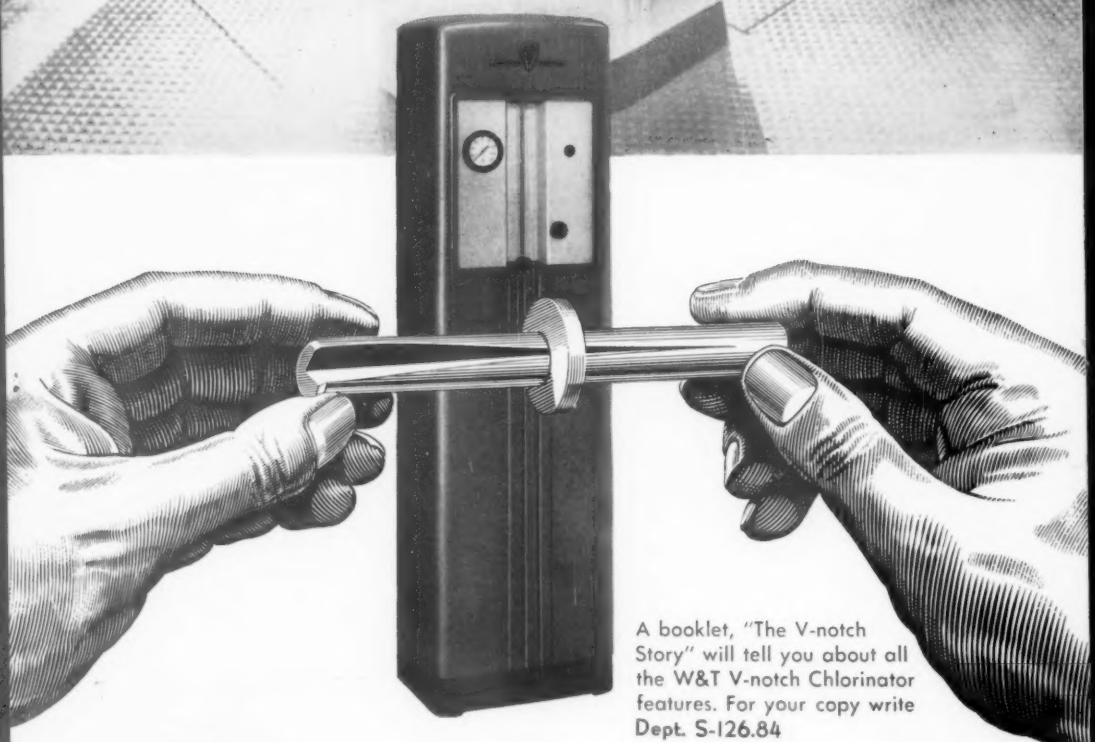

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